EUROPEAN
GEOPHYSICAL
SOCIETY

19980519 038

European Geophysical Society

Annales Geophysicae

Part II
Hydrology, Oceans & Atmosphere

Supplement II to Volume 16

Editorial

Traditionally all abstracts of contributions submitted to the 23rd General Assembly are included free of charge in the *Annales Geophysicae Supplement* once they were accepted by the appropriate convener(s) and once they were received in time, in the standard format and of sufficient quality for reproduction. Abstracts submitted for symposia included in two different parts of the Supplement issue are included (twice) in both parts, respectively.

Like in previous years, not all contributions included will actually be presented. Because of the lack of financial support, several young scientists as well as colleagues from the central and east-European countries will not be able to participate in the meeting, although the Society has continued its support schemes, such as the Young Scientists' Travel Award and the East European Support Award. In this way there are more abstracts included in the *Abstract Book* than contributions compiled in the *Programme Book*. Therefore, in order to simplify the ordering of abstracts within an event, we have adopted the alphabetical order with respect to the surname of the first author rather than the order of presentation in the *Abstract Book*.

With almost 5.800 contributions received, this Supplement of *Annales Geophysicae* has become an important open forum for fast distribution of results of geophysical research on a pan-European, international level, helping, at the same time, to promote the contact between all geophysicists in Europe. Please, support the fostering of cooperation and contact your colleagues also if not personally present this time. For this reason, the authors have also included a contact e-mail or fax number in their abstract for faster correspondence.

On behalf of the Society I am very pleased to welcome you to Nice on the occasion of the 23rd General Assembly of the European Geophysical Society. May your participation in this meeting be successful and scientifically rewarding.

A.K. Richter
Executive Secretary

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	1998	Conference Proceedings

4. TITLE AND SUBTITLE

European Geophysical Society XXII General Assembly, 20 - 24 April 1998

5. FUNDING NUMBERS

F617089

6. AUTHOR(S)

Conference Committee

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Rutherford Appleton Laboratory
Chilton, Didcot OX11 0QX
United Kingdom

8. PERFORMING ORGANIZATION REPORT NUMBER

N/A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

EOARD
PSC 802 BOX 14
FPO 09499-0200

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

CSP 98-1044

11. SUPPLEMENTARY NOTES

Four volumes of proceedings and one volume of newsletters.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

A

13. ABSTRACT (Maximum 200 words)

The Final Proceedings for European Geophysical Society XXIII General Assembly, 20 April 1998 - 24 April 1998

This is an interdisciplinary conference. Topics include meteorology, ionospheric physics, space physics, oceanography, geophysics and geodesy

14. SUBJECT TERMS

Space Science, Atmospheric Science, Ionosphere, Geophysics, Meteorology

15. NUMBER OF PAGES

1546

16. PRICE CODE

N/A

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19, SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

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HSA1 Hydrology and the Earth's crust

01 Characterization and modelling of the 2-D and 3-D structure of porous and fractured formations

Convener: Huggenberger, P.
Co-Convener: Mackay, R.

COMPUTER SIMULATION AND ANIMATION OF WATER MOVEMENT IN SOIL

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The object of the study is modelling and visualizing water movements in soil. A computer programme written by the 2nd author serves this double aim. The mathematical models of the problem are discussed at first, considering how much they are based on the reality and how efficient are they for computer programming. The two realized methods are analysed more detailed. One of them is discretization in space. The basic feature of it is that space is divided into small, elementary cells that can be considered and handled as homogenous (for the model). These cells can be either "holes" or solid "soil-particles". The neighbouring holes stand in a relation given by complex parameters that influence streaming. The cells can be generated either using a uniform grid or by stochastic procedures. A potential-field (resp. the superposition of several one) is interpreted on these cells which makes water to move (e.g. gravitational or electric field). The computing is executed by a modified version of the algorythms using graph and matrix theory developed for the examination of electric circuits. The other realized method is the one using fractal geometry to create a micro- pipeline network inside the modelled soil. The main difference from the first method stands in the selection of the parameters that describe the "pipeline system" in the soil. The calculation and visualization does not differ. The visualization uses the real 3-D methods of a previous programme written by the 2nd author. The programme is written in object-oriented C++ and runs under DOS and Unix.

AN APPROACH FOR REPRESENTATION OF 3D GEOLOGICAL STRUCTURES AND MODELING GROUNDWATER FLOWS

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The Plavinas Hydroelectropower Plant is the largest one in the chain of dams on the major Latvian river Daugava. The main building of the Plant is situated on the soft glacial deposits (moraine) that fills ancient (pre-quarternal) valley of Daugava. The wings of the dam lay on the sandwich-type structure of aquifers and semipervious strata of Devonian age. The whole underground structure is distinctively 3D also due to (i) deposits of deluvial and proluvial origin with high permeability on the declivities of hidden valleys, (ii) multiple injections of concrete suspension in the Devonian aquifers to reduce filtration to nearby quarternal valleys.
The above situation is challenging for modelers of groundwater flows. It contains data sets for building of underground structures (more than 1000 geological survey wells are documented since 1950s) and to verify the model predictions (30 years long observation records of piezometric heads at about 300 wells are available).
The CAD-type data assimilation, processing, and visualization toolset is developed for simulation of 3D anisotropic geological structures. This toolset includes 3D finite-element solver for groundwater flows. Model results are carefully compared with observations.

MODELLING FRACTURE APERTURE GROWTH USING SIMPLE GROWTH LAWS

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We present preliminary results of a study to model general characteristics of the growth of fracture apertures given a simple growth law applied to fracture arrays with simple initial aperture distributions. Our motivation for the work is to understand the evolution of fracture aperture distributions and the development of preferential flow paths in fractured aquifers such as the Chalk of north-west Europe. Head and velocity distributions are calculated in a regular array of fractures for given boundary conditions. The resulting velocities are substituted into an aperture growth-rate law, where growth rate is a function of flow rate. The problem is formulated and coded as an initial-value problem for the growth of the fractures. The flow is considered to be quasi-steady-state. We have investigated the sensitivity of the evolved aperture distributions to changes in the functional form of the initial aperture distribution, the mean and standard deviation of the initial distribution, and the form of the growth-rate law. Feedback between initially uncorrelated aperture distributions and the aperture growth-rate law leads to the development of spatially correlated structures. These include constant apertures parallel to the bulk flow direction and single dominant large aperture fractures. The standard deviation of apertures parallel to the bulk flow direction is a useful tool for characterising structural phase changes.

EFFECT OF THE VARIANCE OF THE PORE SIZE DISTRIBUTION ON HYDRODYNAMIC DISPERSION IN HETEROGENEOUS NETWORKS

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We simulate hydrodynamic dispersion as the result of two independent physical mecanisms : advective transport and molecular diffusion. Advective transport is the deterministic passive motion of solute particles along the streamlines. Streamlines can be uniquely determined in two-dimensional networks using the fact that two neighbouring streamlines cannot intersect. Molecular diffusion is modeled by a three-dimensional random walk. By varying the molecular diffusion coefficient determined by the random walk parameters, we can simulate a broad range of Peclet numbers and investigate several dispersion regimes [Sahimi,1995].
The simulated medium is a periodic arrangement of two-dimensional square networks. In order to isolate pore-scale heterogeneity effect, we used network realizations in which only the variance of the pore size distribution is allowed to vary. Particles are instantaneously injected at one face of the network, and tracked in the medium. Dispersion coefficients are calculated from the statistics of the positions recorded at various times during the transport process.
We observe that dispersion coefficients are related to the level of pore-scale heterogeneity. Our simulations also confirm the restrictive effect of molecular diffusion on dispersion, demonstrated by the decrease of dispersion coefficients with decreasing Peclet numbers. Finally, examining how the dispersion coefficients vary versus time, we observe a transition period at the end of which the dispersion coefficients reach a constant value. This transient regime appears to correspond to a similar transition period of the mean velocity of the particules, which asymptotically approaches the Darcy's velocity. The transition period is strongly affected by heterogeneity, but it does not depend on the dispersion regime.

GAS DIFFUSION IN AN UNDISTURBED SOIL CORE AND IN ITS 3D RECONSTRUCTION

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Gas transport properties inside a porous medium like soil are greatly related to their 3-dimensional geometrical properties and particularly their topological characteristics. We present here a comparison between an experimental gas diffusion study on an undisturbed loamy-clay soil core and a numerical simulation study in a 3D reconstruction of the soil core. The studied system is a loamy-clay soil core (2.4*cm* length and 7*cm* diameter). Self-diffusion experiments with marked molecules allowed the calculation of the free-air porosity (11%), the self-diffusion coefficient ($D = 0.7\,10^{-5} m^2 s^{-1}$) and so, the tortuosity ($\tau = 2.3$). After gas experiments, the soil sample impregnated with a polyester resin and grinded. Serial sections spaced 100 μm apart were superimposed in order to build a 3-D reconstruction of the soil core. A topological study showed that the connected porosity was 20%. Inside this connected porosity, gas diffusion transfer was simulated with the help of the self-diffusion propagator in order to determine the self-diffusion coefficient in the 3D reconstructed sample and so, of the tortuosity. Comparisons between the experimental and the numerical results allowed the discussion on scale effects on gas transport.

THE IDENTIFICATION OF POTENTIAL FLOWING FEATURES FOR A CONCEPTUAL MODEL OF FRACTURE FLOW AT SELLAFIELD

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Nirex has studied in detail the geology and hydrogeology at a site near Sellafield in Cumbria, NW England to determine the suitability, or otherwise, of the site as the location for a deep repository for intermediate-level and certain low-level radioactive wastes. A key factor in determining site suitability is the nature of groundwater flow in the repository host rock; the Borrowdale Volcanic Group. In the host rock, flow takes place predominantly through a limited subset of discontinuities, mainly fractures, parts of which form networks of connected channels. The conceptualisation of the flow system must be soundly based on site characterisation data as a prerequisite for any numerical modelling study. In this presentation, we will describe how core characterisation studies were used to identify the location, orientation and mineralogical characteristics of the particular discontinuities referred to as potential flowing features (PFFs). These features have either demonstrable present day connected porosity or display evidence of relatively recent groundwater activity. The PFF information has been integrated with data derived from hydraulic testing to provide the basis for robust conceptual models which will be described here and which have been used in a performance assessment of the site.

TRANSPORT PROPERTIES OF FAULT NETWORKS INSIGHT FROM A POWER LAW LENGTH DISTRIBUTION MODEL

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We address the characterisation of flow and transport in fractured media with evolving scales. We use a power law length distribution as a canonical model for fault networks to understand the role of faults of different sizes. The geometric and hydraulic properties of such systems in the vicinity of the crossover from the non connected to the connected state turn out to be different from the results of the percolation theory. This discrepancy stems from the existence of some structures, which typical size can be of the order the of the bulk network size. Although second order phase transition, which is basic to percolation theory, does not seem to be strictly relevant, we retain its main idea to find a simplification of the networks suitable for the characterisation of transport processes in systems presenting large spatial correlations. In order to achieve the study of the flow in this peculiar geometry, we need to define a statistical framework, able to both encompass this new variety of structures and model its consequences on the variability of the predictions. We finally perform pump tests to feature with more accuracy the scale properties of the fault networks. These tests will also permit to anticipate the identification and simulation capabilities of our model.

THREE-DIMENSIONAL CHARACTERIZATION OF A REAL FRACTURE NETWORK: RECONSTRUCTION, GEOMETRY, TRANSPORTS.

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The dark grey hercynian La Peyratte granite is located in Deux-Sevres (central France). It is fine-grained (1 to 2 mm long crystals) and is crosscut by numerous fractures surrounded by discoloured alteration haloes. The fracture network in a 0.66 m^3 block was reconstructed in three dimensions from digitized images of nine serial sections, where traces of permeable fractures had been identified based on the width of the alteration zone.
A triangulation of the whole network was built, which allows three-dimensional visualizations and the determination of various geometrical and transport properties. Connectivity and percolation was studied, as well as block partitioning. Fluid flow and convective-diffusive mass transport under various external conditions can be simulated by solving the local transport equations in the fracture void space. The effective transport coefficients are evaluated, and three-dimensional flow maps are visualized.

DEVELOPMENT OF PERMEABILITY IN FAULT ZONES

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Large faults are commonly major water conduits in solid rock. Most faults develop from smaller fractures, commonly sets of joints. An active fault can increase the average permeability of a site by several orders of a magnitude, but the permeability changes much during the fault development. A study of the hydrogeological characteristics of a 5-10 km wide and around 100 km long dextral strike-slip fault zone in Iceland, active for nearly 10 Ma, shows that the original permeability of the basaltic lava pile, primarily due to columnar joints and scoria layers between the lava flows, has been substituted by high and low permeability subzones within the main fault zone. High permeability is characterised by intense sets of cross-cutting mineral veins, due to transmission of geothermal water, whereas low permeability is represented by completely crushed rocks. Field and theoretical studies indicate how the location and controlling stresses of these subzones have changed during the development of the main fault zone.

GEOMETRIC MODELLING OF FRACTURE SYSTEMS: APLICATION TO DIFFERENT GEOLOGICAL TARGETS.

P. Gumiel (1), R. Campos (2) & J.J. Durán (1)
(1) I.T.G.E. (2) C.I.E.M.A.T.

The geometric modelling of the fracture systems, in base to their fractal scaling properties, spacing, frequency, density and aperture, together with the directional analysis of the different sets, has great importance in many fields of geological applications. Detailed studies of fracture networks attempt to predict connectivity, which tend to increase deformability and permeability of a fractured rock mass. Several cases of application of fracture analysis in Spain are presented in this work, including the characterization of connected veins systems, capable to produce a mineral concentration, (for example, Au, or W-Sn, mineralized vein groups, as well as the pyritic stockworks of the Iberian Pyrite Belt), until the discrimination of connected fracture networks, which favour fluid flow, of great interest in the definition of storage zones to industrial residuals. To this respect, the analysis of fracturing in several mines is also presented, (for example, Villabona, Moscona in Asturias, and the Castellar in the Toledo province). Finally, geometric analysis of fractures is also of major importance in karstic and hydrological studies, because in most of the cases, the fractures exercise a marked control in the distribution of caves (for example, in the Betic Cordillera, Southern Spain), or channelling groundwater.

A SIMPLIFIED NUMERICAL MODEL COUPLING FLUID FLOW, HEAT AND MASS TRANSFERS AND GEOCHEMICAL REACTIONS IN SEDIMENTARY BASINS

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When a fluid containing dissolved species is slowly flowing through a heterogeneous temperature field, dissolutions and/or precipitations might occur in order to maintain thermodynamical equilibrium with the minerals composing the solid phase.
In this work we present a simplified numerical model simulating those coupled phenomenon using the finite element method.
The flow is controlled by the boundary conditions (2D or 3D gravitational flow) or by the fluid density variations (2D free convection). Heat transfer is mainly due to conduction whether mass transport is essentially convective. The fluid being always in equilibrium with the solid phase, the concentration of the different dissolved species is a function of temperature only.
2D and 3D examples are presented to illustrate the comportment of the feedback existing between fluid flow and geochemical reactions through the permeability field evolutions. Consequences on the structure of the porous formations are discussed and the possibility of backward simulations is examined.

UPSCALING AND CALIBRATION IN THE NIREX 97 ASSESSMENT OF THE PERFORMANCE OF A REPOSITORY AT SELLAFIELD

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Nirex has recently completed a new assessment of the performance of a hypothetical radioactive waste repository at Sellafield. In this paper, the derivation of effective hydrogeological parameters for use in numerical flow and radionuclide transport models for Sellafield is presented. A combination of calibration and upscaling from data on a range of length scales was used. The underlying structure of the variability in the hydrogeological parameters was taken into account, with particular attention paid to geological understanding. The information from upscaling was combined with that from calibration, that is determination of ranges of the parameters that give an acceptable match to data independent of those used in upscaling. A key aspect of the analysis is a systematic treatment of uncertainty, both in upscaling and in calibration. The approach is illustrated for the potential repository host rock, where groundwater is considered to flow mainly in a subset of the total set of discontinuities. This subset (the Flowing Features) can be identified in boreholes by open porosity or by the presence of recent (in geological terms) calcite. In boreholes, the Flowing Features are strongly clustered, which appears to have hydrogeological significance. Both analytical and numerical network models were used to derive upscaled permeabilities and porosities. A key uncertainty was the connectivity of the clusters, which was taken into account. Calibration was then used to update the parameter ranges.

SURFACE GEOPHYSICS APPLIED TO PERMEABILITY DISCRIMINATION, CHARACTERIZATION AND SITE MODEL DEVELOPMENT

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Radio Magnetotelluric-Resistivity (RMT 12 to 240 kHz) and Very Low Frequency-Electromagnetic (VLF-EM) surveys were used to characterize and discriminate between different porous media depositional environments as part of a site selection process. Despite extensive data for the prolific Seeland aquifer (Switzerland, BE), most data were too far apart to locally distinguish the differences in important sedimentary structures, erosion surfaces and permeability resulting from the area's complex depositional history. Continuous VLF-EM profiles and RMT data identified geologic heterogeneity over about 3km at six sites (Canton Berne). A 1-D interpretation model of VLF-EM data yielded profiles with highly variable resistivity, underlying aquitard depth and topography at four of six sites. Interpreting the 2-D RMT data (20m spacing) confirmed these differences in the sedimentary materials and yielded patterns of buried river channels and aquifer /aquitard surfaces. The other two sites had more uniform aquitard depths and topography. Land ownership issues and aquifer depth resulted in the selection of one 'preferred site' where detailed VLF-EM profiles and RMT (>300 points, 5m to 20m, 8000m^2) measurements were made. RMT and VLF-EM data were combined to prepare a 3-D variability model of site aquifer thickness (12m to 18 m), aquitard topography (channel and ridge), and preferred permeability pathways (high resistivity). Drilling at 7 points confirmed aquifer depth, silty aquitard and gravelly aquifer resistivity interpretation. Modeling site ground water flow and transport will include structure and permeability from this geophysical characterization.

SYSTEM CHARACTERISATION FOR MODELLING CONTAMINANT TRANSPORT IN MULTI-SCALE FRACTURED PERMEABLE AQUIFERS

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Correct characterisation of multi-scale fractured formations in terms of multi-continuum modelling is crucial for assigning the correct type of numerical model for simulating contaminant transport. Multi-scale fractured formations comprise different hydraulic components causing the heterogeneous character of such systems (fracture sets on different scales and rock matrix). In the multi-continuum approach the integral system is separated into coupled homogeneous continua, each representing one component. Definition of equivalent parameters and description of exchange processes between the components is essential to the principle on homogenisation of multi-continuum systems. Especially appropriate simulation of exchange processes is highly dependent on the applied numerical model. A technique for reliable system characterisation and model identification is presented to determine the number of relevant components and the type of exchange process. The study is based on coupled field, laboratory and numerical transport experiments for a fractured permeable sandstone block (10x7x2 m) in southern Germany. A combination of hydraulic and geometric properties as well as transport response characteristics are identified as indicators in the characterisation technique. The study is performed by a co-operation of in total four experimenting and modelling groups.

CHARACTERISATION AND MODELLING OF QUATERNARY OUTCROP ANALOGUES

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As experience from test sites such as Bordon, Cape Cod and others shows, the subsurface characterisation of aquifers is often insufficient for detailed reactive transport predictions. In particular, high resolution, hydraulic and hydrogeochemical aquifer data is required for accurate groundwater risk assessments, clean-up studies or the optimisation of investigation methods.

The outcrop analogue study presented here - a detailed sedimentological interpretation and hydrogeological characterisation of Quaternary sand and gravel outcrops - led to a database of hydraulic conductivities, porosities and kinetic parameters for each lithological facies present in the outcrops. This new approach incorporates *in situ* and laboratory measurements by hydraulic, pneumatic, geophysical, hydrogeochemical and sedimentological methods. The resulting 2D high-resolution data sets represent a very detailed database of excellent quality.

On the basis of one example from an outcrop in southwest Germany the process of building up the database is explained and the results of modelling of transport kinetics in such heterogeneous formations are presented and discussed.

The project is part of a special research programme funded by the German Science Foundation (DFG).

NUMERICAL MODELS OF KARST DRAINAGE SYSTEMS

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We study large-scale evolution and flow in fractured karst aquifers by means of numerical modeling techniques. The flow in a fractured network of conduits and their subsequent enlargement through time as a result of calcite dissolution within the medium is solved using an irregularly distributed network of conduits, based on the natural neighbours approach. The geometric flexibility of this method, along with a simplified approach describing the dissolution process of limestone from the conduit walls, enables us to study both laminar and turbulent underground flow in a karst aquifer in its early stages. Preliminary modeling results performed in two dimensions agree well with observed drainage patterns in karst landscapes and thus encourage us to extend the simulations to three dimensions and to include more geologically oriented boundary conditions.

CHARACTERISING ZONES OF LOCALLY ENHANCED CONDUCTIVITY FROM PUMP TEST DATA

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The identification of large scale flowing features with enhanced hydraulic conductivity is of particular importance to performance assessment calculations for radioactive waste disposal. Extensive zones of locally enhanced conductivity (ZLECs) can provide rapid pathways for radioactive waste transport from a deep repository to the ground surface.

This research was commissioned by the Environment Agency of England and Wales (EA) to investigate the characterisation of ZLECs from borehole pump test observations. PARADIGM is a three dimensional, density dependent, saturated, flow and transport model developed for the EA for performance assessment of deep radioactive waste disposal sites. It is ideal for investigation of ZLECs, since it contains a detailed fracture flow representation. PARADIGM has been employed to simulate the response at a borehole from a single ZLEC within a surrounding matrix block of lower conductivity. The pumping interval in the borehole is placed at different proximities to the ZLEC and the simulated pressure responses in the interval are analysed to determine characteristic response signatures. It is anticipated that the results of these investigations will help both in the interpretation of pump test data and in the design of pump tests for identification of nearby features, such as faults, as zones of locally enhanced conductivity.

Testing the validity of the HSSM KOPT model by simple laboratory column experiments using differently structured soils

MAKÓ, András - PATE University Keszthely, HUNGARY

Laboratory infiltration column experiments were made to expand our experimental data base. The experiments were performed with four type of soil samples (sand, loess and two aggregated subsoils) using four type of liquids (distilled water, isooctane, cyclohexane and paraffin oil). The specific objectives of this research were: (1) to find easy experimental techniques to simulate spills in differently structured unsaturated media, (2) to perform spill simulations in one-dimensional column systems and generate a data base on the vertical movement of NAPLs in the unsaturated zone, (3) to test the HSSM KOPT model against the experimental results, (4) to evaluate the effect of the degree of aggregation on the simulation results. There was established that quantitative agreement of HSSM KOPT simulations with the experimental results depend on the accuracy of the input parameters. The results of the simulations were depended primarily on the saturated hydraulic conductivity. The estimation of this parameter is based on the result of our former measurements. The results show, that - as far as NAPLs are concerned - in structured soils the degree of aggregation is the factor which fundamentally determined the hydraulic conductivity. Therefore, in the case of structured samples, some modifications were made on the settings of the model, according to our earlier investigations, to use the real hydraulic conductivity values during the simulation.

USING THE AQUIFER ANALOGUE PRINCIPLE FOR THE INVESTIGATION OF THE FRACTURED POROUS SYSTEM :- NEW TECHNIQUES AND MODELLING CONSIDERATIONS.

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New laboratory and sample recovery techniques are presented enabling the determination of the three dimensional physical parameters of undisturbed fractured porous sandstone bench scale samples, (30cm diameter x 40 cm length). Gas tomographical experimentation with helium as a tracer in a specially designed experimental cell provides different scaled information which is then combined to give an analogue of the fractured aquifer. Analysis of the results to date using a multi-shelled model have shown that the dimensionality of the flow field as well as the structure of the sample plays an important role in the understanding of the system.

UNSATURATED MEDIA STUDY IN SOILS WITH MACROPORES THROUGH PSEUDO-SATURATION APPROACH: AN APPLICATION IN BASALTIC *TERRA ROXA ESTRUTURADA* SOIL, SOUTHERN BRAZIL.

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In this work, an alternative approach of bimodal porosity distribution for experimental $\theta(\psi)$ relations in heteregeneous soils is presented. The method tries to identify i) the pseudo-saturation volumetric content, θps, which not only represents relative macroporosity, ξ, but also influences hydraulic characteristics of unsaturated media, ii) equivalent diameter of the main subsystem, d_{e1} and iii) equivalent diameter of the macropores' subsystem, d_{e2}, iv) and van Genutchen mathematical constrains are satisfied. The relative macroporosity is defined through the relationship betwen the volumetric macroporosity and the total volumetric capacity. The two hypothesis are: i) that the whole retention curve can be described by the combination of two simple curves acting in differentiated parts of (θs-θr), ii) the derived relative hydraulic conductivity curve is corrected due to which pore domain, principal or secondary, is being analysed on. This methodology is performed over 30 $\theta(\psi)$ experimental curves, ranging from the top surface to the first 100 cm deep horizons, on a rich clay, farming *Terra Roxa Estruturada* soil of the Sulriograndense Basaltic Plateau, Southern Brazil. These soils are located in an agriculture hillslope, with conventional tillage, showing evident swelling effects as well as with macropore dynamics in upper horizons. The results show evidences of a second system that represents one third of the underlying soil water storage capacity. The experimental results showed preliminar evidences that pseudo-saturation method discriminate more easily the fraction of pores in the soil that can have a dual behavior, related to macroporosity effect.

Alternative Geostatistical Models of Contaminated Soil Stratigraphy

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Interpolation of measured data on lithology at shallow contaminated land sites is an important requirement for both the economic development and validation of remediation schemes. The potential for improved estimation of regions of contamination using flow and transport models requires knowledge of the spatial character of the hydraulic properties of the soils. The number of trial pits and auger holes used at most sites is sufficient for the application of spatial statistical methods of characterisation. This is particularly true wherein models of lithological variations alone are required.

A site is used which has been sampled with 146 trial pits on an area of 80 ha. The lithological data from these pits have been used to set up two geostatistical models. A further 200 boreholes on a regular grid over the domain have been constructed to provide a validation of the remedial actions undertaken. This second data set provides an independent validation of the models. Using the two data sets the effectiveness of the two truncated Gaussian models has been examined. The approaches used to construct the underlying mathematical models and the uncertainty in the underlying models have been addressed. The results show the importance of including soft data in the definition of the statistical models underpinning both methods in order to define the anisotropy of the soil structures forming the region.

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DETERMINING A SUITABLE FRACTURE NETWORK MODEL AS A BASIS FOR GROUNDWATER-MODELLING IN A FRACTURED CRYSTALLINE AQUIFER

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The modelling of groundwater flow in a high mountainous region poses many questions concerning the influence of e.g. glaciation and seasonal variations on groundwater recharge, residence time of the groundwater, and groundwater contribution to the overall run-off. Modelling the groundwater flow through a fractured media requires the consideration of aspects such as preferential flowpaths versus matrix flow, the validity of flow equations and particularly the distribution and connectivity of the discontinuities. The objective of the underlying project to this presentation is to evaluate and model the groundwater flow through fractured crystalline rock in high mountainous regions. A study area of approximately 24 km^2 was chosen in the western part of the Gotthard-massif (Switzerland) consisting dominantly of the late hercynian intrusive Rotondo-Granite between elevations of 1500 m to 3200 m. This poster presents the collected data of the fracture distribution from surface outcrops, subsurface excavations and aerial surveys, as well as the statistical analysis of these parameters. Investigations of the geostatistical and fractal properties of the fracture distribution are shown, and an outlook for the most suitable approach, accommodating the objective of the overall project, is presented for discussion.

A NEW APPROACH TO SEDIMENT EROSION AND DEPOSITION IN AN ALLUVIAL SYSTEM.

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One method used to reach geologic formation heterogeneity is simulating sedimentary processes. The aim of this method is to reconstruct the complexity with a genetic view point. The new approach presented here is a multi-agent model applied to alluvial deposits. On the basis of empirical observations on flume and hydrodynamic equations, we determine a set of global rules of sedimentation and erosion in an alluvial system. We divide the sediment load into a few lithologies (gravel, sand or clay). Each « particle » of a given lithology moves along the river and « decides » for itself to sediment according to its neighbourhood information. Erosion takes place in the same way. A « particle » represents an elementary volume of sediment, this volume depends on its lithology. This model is tested in a meandering environment of an alluvial system and it shows bend migration with point-bar deposits, cut-offs and the filling of oxbow-lakes.

NUMERICAL SIMULATION OF THE FLOW AND TRANSPORT OF NAPLS IN HETEROGENEOUS POROUS MEDIA

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The flow and transport of nonaqueous phase liquid (NAPL) contaminants is particularly sensitive to spatial variability in hydraulic properties. Thus challenges of parameter identification in real aquifer systems lead to difficulties in the prediction of the fate of NAPLs in the subsurface. However the spatial distribution of residual phase and/or pools has direct consequences on the rate at which the NAPL partitions into the groundwater, which again has important implications for the clean up of contaminated sites: the rate at which the dissolution processes occur determines the efficiency and duration of remediation efforts, e.g. by pump-and-treat, or the bioavailabilty of the contaminant for degradation. Since statistically-generated conductivity fields often do not appear to closely resemble the structural characteristics of sedimentary deposits, in this study the release of a NAPL and its subsequent migration in highly heterogeneous sand and gravel deposits is simulated for a data set formed by the interpretation and mapping of sedimentary structures observed in an outcrop. As a comparison, the ability to predict the resulting dissolution characteristics using conductivity fields generated by geostatistical techniques is assessed.

USING PRECORRECTED RAW DATA IN COMPUTER TOMOGRAPHY TO QUANTIFY STRUCTURES IN DENSE POROUS MEDIA

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In contradiction to colouring and impregnation techniques, Computer Tomography is a nondestructive technique which can provide 2 and 3 D images of porous media. Therefore it is a powerfull tool to characterize porous media and derive proper parameters for modelling purposes. However, before this technique can be used as a full quantitative technique for dense porous media (f.e. soil, mortar), some drawbacks from this medical technique should be solved. In this research a profound investigation of the beam hardening effect, which influences the quantitative interpretation for porous media, was carried out. Well known phantom objects (glass, PVC and plexiglass cylinders) with and without air inclusions were used for this purpose. A program was written to precorrect raw data before reconstructing images of these dense materials wherebye the chemical composition and the weighting coefficients of the different components are the input parameters. A major improvement was achieved in reducing the beam hardening effect using the precorrection and material specific program for homogeneous phantom objects. These results are very promising to use this medical technique for non-medical purposes such as the (exact) quantification of pores and fractures in dense materials.

MC SIMULATION OF TRANSPORT IN 2-D HETEROGENEOUS ANISOTROPIC MEDIA WITH THE FLOW ORIENTATED IN AN ANGLE

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The development of a plume of solutes injected in a stochastic anisotropic medium is studied when the flow is orientated in an angle with the main direction of anisotropy. Of specially interest is the angle that the main axes of the plume will develop compared to both the direction of the mean flow and the anisotropy. A 2-D numerical Monte Carlo approach (500 real.) is followed. The anisotropy ratio of the hydraulic conductivity field, λ_x/λ_y, is 5 and the size of the field is $21\lambda_x$ and $108\lambda_y$ in resp. the x- and y-direction. 800 conservative solutes are injected instantaneously in one node and local dispersion is considered. The position of the particles and spatial moments are recorded periodically. The simulation results in a width range of plume sizes both in terms of displacement of the center of mass as in terms of the dispersion around these centers. The distribution of the hydraulic conductivity field is found decisive for the evolution of the plume. The angle of the plume goes in general offset from the mean direction of the flow in the direction of the anisotropy. Both if we look at the distribution of the particles in all the realizations (400,000) as when we consider the realizations separately. The former turns eventually to the mean flow direction. The last however stays even after large travel times offset in the direction of the anisotropy. The results do not coincide with the ergodic hypothesis.

DESCRIBING AND CHARACTERIZING MACROPOROSITY IN A LOAM SOIL USING DYES TO PREDICT SATURATED HYDRAULIC CONDUCTIVITY

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Nowadays, there are several techniques available to characterize porous features in structured soils. Adding colored dyes under ponding conditions is probably one of the most known and 'easy to use' techniques to visualize macropore patterns. In this research, a 0.1 % concentrated MB dye solution is added under ponding conditions to 20 saturated soil cores (20-cm ID and 20-cm long). Different size and shape variables were used to characterize macroporosity at three different depths and two different scanning resolutions using a set of size and shape variables described in literature. Macropores were also divided into different size groups following a circularity index criterium. Differences between mean values of the variables at the three depths and between different scanning resolutions were statistically investigated. Later on, macropore pattern variables were calculated and used in a regression analysis to predict the saturated hydraulic conductivity. Results show a discernible difference between depths for some size and shape variables indicating different structures and between resolutions indicating the importance of the methodology. Generally, the macropore pattern variables (for all macropore groups and scanning resolutions) calculated from individual size variables have the largest correlation coefficient with the saturated hydraulic conductivity.

A FINITE ELEMENT ALGORITHM FOR SIMULATING GROUNDWATER FLOW, HEAT AND CONTAMINANT TRANSPORT IN DISCRETELY FRACTURED ROCKS

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Previous studies on groundwater flow and contaminant migration in discretely fractured earth media have examined forced convection. Density differences between contaminated fluid and ambient groundwater have largely been ignored. Density differences can result from variations either in solute concentration or in temperature. We fully integrate the coupled time-dependent fluid, solute and heat transport equations for discretely fractured porous media, develop a finite element algorithm to solve these equations and investigate the behaviour of non-linear convective mechanism of contaminant transport. The numerical experiments indicate that density variations of contaminated groundwater can drive fluid convection even if there are no external forces. The strong density contrast between the ambient groundwater and the invading contaminant plume promotes downward advection of the contaminant plume and a return flow of less dense material. The multiply fractured models are comparable to uniformly anisotropic models as long as both have the same averaged permeabilities and other physical parameters. It is confirmed that in typical field conditions where fracture apertures and spacings are non-uniform and commonly unknown, plume patterns and migration rates and directions for variable-density dissolved contaminant are very difficulty to predict.

02 Identification of model parameters in groundwater hydrology

Convener: Giudici, M.
Co-Convener: de Marsily, G.

HEADS AND DENSITIES FOR CALIBRATING A MODEL OF A LOW PERMEABILITY GROUNDWATER SYSTEM

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Groundwater heads and densities were among the data that were used to calibrate a regional-scale model of a low permeability, variable density, groundwater system as a location for a repository for radioactive waste. This paper describes the derivation of these data with appropriate uncertainty ranges. Environmental heads are derived from environmental pressures and groundwater densities. Environmental pressures were obtained from hydraulic tests over discrete intervals in boreholes and by subsequent monitoring. Uncertainties in the interpreted pressures from hydraulic tests can be relatively large for low permeability intervals. They were estimated for some tests by test simulation software, and in the other tests by using an inverse correlation between uncertainty and permeability. Densities were estimated from chloride concentrations, which had been measured on water samples taken from specific test intervals. Contamination of samples with drilling fluids was monitored by use of a tracer. Uncertainty in density derives from uncertainty in the actual groundwater composition and in the empirical relationship between chloride and density, and also from interpolation of vertical density profiles. Calculations of heads and densities were integrated and uncertainties were propagated probabilistically. The dominant sources of uncertainty are (i) interpretation of hydraulic test pressure data, and (ii) correction of groundwater sample compositions for contamination. Ranges in head values vary from ±2 to ±40 metres, and are up to ±5 $kg{\cdot}m^{-3}$ in groundwater density values.

ASSESSMENT OF TRANSMISSIVITIES IN ARID ALLUVIAL BASIN BY A MIXING CELL MODEL APPLIED TO SPATIAL HYDROCHEMICAL AND ISOTOPIC DISTRIBUTION IN GROUNDWATER

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A mixing cell mathematical model was applied to assess transmissivities and quantify subsurface fluxes in an arid basin with complex hydrogeological structures for which scarce physical hydrologic information is available. The model is based on spatial distribution of environmental tracers such as dissolved minerals and relies heavily on stable isotopes of O-18 and D. It is assumed that spatial variations of ions and isotopes in the aquifer can be attributed to mixing and dilution of several sources of groundwater recharge. Tracers are assumed to be conservative along the flow path. The flow domain is divided into discrete mixing cells based on the distribution of the dissolved constituents. Environmental tracers are then used to write a set of water and mass balance equations in a compartmental flow system, such that the unknowns are transmissivities, groundwater fluxes and sources of recharge. Quadratic programming is applied to assess the above-mentioned unknowns. The model has been tested for multi-cell flow systems with synthetic data and known solution. Later, the model was implemented in the alluvial basin of the southern Arava Valley located north of the gulf of Eilat shared between Israel and Jordan. Results indicate that the calculated transmissivities for the alluvial aquifer of the Southern Arava are close to what was obtained with interference, recovery and draw-down pumping tests prevailing in the southern Arava basin.

PREDICTION OF THE WATER RETENTION PROPERTIES OF SOILS: PERFORMANCE OF AVAILABLE PEDOTRANSFER FUNCTIONS AND DEVELOPMENT OF NEWS APPROACHES.

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The objectives of this study are to evaluate the validity of six earlier published pedotransfer functions (PTFs) in order to estimate the water retention properties of soils of France, and to develop new PTFs when the available ones are not appropriate.These PTFs require various combinations of soil characteristics: particle size distribution, bulk density, soil water content values at −330 hPa and at −15000 hPa and soil organic matter or carbon. They were tested using data for nearly 400 soils located mostly in the Paris basin and on the Mediterranean coastal plain. We measured the water content on clods $5-8cm^3$ in volume at 8 values of matric potential ranging from −10 to −15000 hPa. The first results show that the performance of the tested PTFs was largely variable, from acceptable to extremely bad. The difference in performance of the tested PTFs could not be related to the number or kind of basic soil characteristics they used as predictors.The actual work tends to take into account the nature (granulometry and mineralogy) and fabric (coarse-fine fractions relationships) for the establishment of PTFs which would be not exclusively based on statistical relationships but on a more mechanistic approach.

WHAT IS WRONG IN THE KOZENY-CARMAN APPROACH?

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Since the celebrating works of Slichter, Blake, Kozeny, Carman and their followers (see the books of Adler, Bear, Dullien, Kaviany, de Marsily, Romm, Scheidegger for further references) conductivity evaluations are based on solution of the viscous flow (Poisson) equation in a tube with either non-slip (saturated regime) or free surface (moisture flow) boundary conditions. Similarly, the Taylor-Aris theory of dispersion involves the mean velocity as an averaging of the 'parabolic profile'. We show that the standard averaging of velocity over the tube (equivalent to pore) area can lead to erroneous results. Namely, for a wide variety of geometries (typical in fractured media or non-saturated regimes) the standard 'mean velocity' is zero. We establish rigorously the minimal total conductivity for a two phase flow through a bundle of capillaries of various cross-sections using the Dirichlet, Newman, and 4-th type boundary conditions. From rigorous solutions of the Stokes and Navier-Stokes equations in the 2-D case we derive the medium conductivity by composition of 'structural elements' - bends, orifices, and common 'cubic law' smooth fracture segments. The corresponding results are compared with approximations of the lubrication theory. For tracers spreading within fractures, a method of coupling of a bulk 'kernel' region where flow takes place with practically stagnant Turner-type zones is proposed.

THE MODEL OF WATER EXCHANGE BETWEEN CASCADE OF RADIOACTIVE WATER RESERVOIRS OF TECHA RIVER (SOUTH URAL) AND GROUNDWATER, AS THE TOOL OF VERIFICATION OF BALANCE CONSTRUCTIONS.

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The analysis of the Techa River Radioactive Reservoirs water balance shows, that the data on volumes of groundwater receiption into the reservoirs and value of filtration losses from them is the most poorly investigated. At the same time this part of the water balance can be large and sometimes close to surpass values of radioactive waste leakages. Hydrological-filtration model can serve as independent tool for fulfilment of expert valuations connected with the question on interrelation between researched reservoirs and groundwater. The created model helps to explain the dynamics and directions of the processes and allows to specify balance accounts.

RELIABILITY OF TRANSMISSIVITY MEAN AND VARIANCE ESTIMATION BY PROCESSING A LIMITED SET OF DATA

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This study aims to define the reliability of the parameter estimation of the transmissivity probability density function in heterogeneous 2-D aquifers.
The work hypotheses are that a limited set of measurements is available for parameter estimation, the transmissivity is log-normal distributed and the integral scale is finite. The investigated parameters are the mean and variance of the log-transmissivity.
The analysis of the parameters reliability is carried on with regard to the density of measurements both regularly and randomly spaced, the size of whole investigated domain and the methodology of parameter estimation.
A theoretical analysis, based on the theory of random functions is developed and the finds are compared with the results of a Monte Carlo process.
With regard to the methodology of parameter estimation, the simple method of moments and a method based on geostatistical theory are compared.

STOCHASTIC INVERSION INTEGRATING EXHAUSTIVE GEOPHYSICAL DATA IN A NON-GAUSSIAN FRAMEWORK

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The difficulty and even impracticability of exhaustively measuring hydraulic conductivity (K) over a dense grid leads to perform field surveys which yield other parameters that can be related, through correlations or trends shown by scattergrams, with K. If this information is properly incorporated in the inverse problem techniques can provide a way to better identify model parameters and then to improve the characterization of the uncertainty of flow and mass transport predictions. A new technique to incorporate secondary information in the stochastic inversion of piezometric data is presented. It does not required to assume the classical multigaussian hypothesis for the K field and can also incorporate soft data like those coming from the expert judgement or general geologic considerations. It preserves the connectivity of extreme conductivity values accounting for all the available primary and secondary data. The methodology is applied to study the uncertainty of flow and mass transport predictions using the MonteCarlo method. The case study corresponds to a synthetic aquifer with a non-gaussian K field and secondary information along several seismic lines. The simulations are done assuming different data scenarios. Results prove the practical possibilities of the method and the importance of incorporating secondary data in the stochastic inversion.

ON THE GEOSTATISTICAL INVERSION OF INTERFERENCE TESTS

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Transmissivity estimates derived by means of Jacob method are independent of the observation well location (Meier el al, 1998). Moreover, estimated transmissivity appears to be very close to its effective large scale value, rather than to the geometric average of point values, at least for the stationary fields they tested. This finding might suggest that one cannot derive variability patterns from multiple well pumping tests. Actually, information on varibility is provided by the time intercept of Jacob's semilog plot and by the early time shape of the drawdown curve. In order to test whether this information is sufficient for defining heterogeneity trends, we performed geostatistical inversion of both synthetic and real pumping tests performed on heterogeneous media with several observation wells. The conclusion of our work is multifold: (1) the most significant heterogeneity patterns within the test area can be identified; (2) the test provides little information outside the region covered by the observation wells; (3) the shape of the regions of high transmissivity is highly sensitive to the assumed heterogeneity structure.

EVALUATION OF PREDICTION INTERVALS FOR EXPRESSING UNCERTAINTIES IN GROUNDWATER FLOW MODEL PREDICTIONS

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We tested the correctness of 95% individual likelihood-method prediction intervals for hydraulic heads, streamflow gains, and effective transmissivities computed by groundwater models of two Danish aquifers. To compute the intervals, we assumed that each predicted value can be written as the sum of a computed dependent variable and a random component that is a composite of small-scale variability and errors such as measurement errors. The small-scale variability adds to the computed dependent variable because the model parameters commonly represent only important, or large scale, hydrologic and geologic features of the actual system. Testing was accomplished by using a cross-validation method, and by using new field measurements that were not used to develop or calibrate the models. The tested null hypotheses are that the actual coverage probability of the prediction intervals is not smaller than the nominal probability (95%) and that each actual tail probability is either not larger or not smaller than the nominal probability (2.5%). In all the cases tested these hypotheses were accepted at the 5% level of significance. We also tested and accepted the hypotheses using linearized approximations of the prediction intervals, because the nonlinear and linear intervals in most of the cases were nearly identical. We conclude that for the groundwater models of two real aquifers the coverage and tail probabilities of the prediction intervals appear to be correct.

IDENTIFICATION OF ZONES AND GROUNDWATER PARAMETERS AT A HETEROGENEOUS AQUIFER, USING A 3D INVERSE FLOW AND TRANSPORT MODEL.

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A site near Columbus, Mississippi has been the location for intensive studies of flow and transport in heterogeneous aquifers. A large amount of data including hydraulic heads, hydraulic conductivities, and tritium concentrations from a controlled injection have been collected during the MADE experiments. The use of a three-dimensional inverse groundwater model including simultaneous estimation of flow and transport parameters was proposed to help identify the dominant characteristics at the site. Simulations show that using a hydraulic conductivity distribution obtained from 2187 borehole flowmeter tests directly in the model produces poor matches to the measured hydraulic heads and tritium concentrations. Alternatively, using time averaged hydraulic- head maps to define zones of constant hydraulic conductivity to be estimated improves the match to the measured hydraulic heads, but the match to tritium concentrations is still poor. Finally, including conservative transport information obtained from the measured tritium concentrations to adjust the zonation pattern implies the overall best matches. Inverse results show that many of the major plume characteristics can be explained by large-scale heterogeneity in recharge and hydraulic conductivity.

TEMPERATURE - CARBON DIOXIDE PARTIAL PRESSURE TRENDS IN CONFINED AQUIFERS

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What mechanisms control the carbon dioxide partial pressure (Pco_2) at depth ? Transformation of organic carbon ? Equilibrium with carbonates ? Magmatic flux ? More than 500 published data of Pco_2 were collected for solutions from about 30 confined aquifers. The Pco_2 data plotted *vs.* temperature (T) are clearly grouped into two curves. The lower curve corresponds to magmatic rock environment, the Pco_2 varies from 10^{-6} to 50 bars when T increases from 10°C to 300°C. The higher curve corresponds to sedimentary environment, the Pco_2 varies from $2 \cdot 10^{-3}$ to 130 bars when T increases from 10°C to 200°C. Such trends of Pco_2 can be computed thermodynamically by expressing CO_2 as a function of mineral phases (m_j) and their stoichiometric coefficient (α_j) : $CO_2 \Leftrightarrow \Sigma_j\ \alpha_j\ m_j$ where the set of minerals is either {calcite, Ca-Al-silicate, other silicates} or {calcite, dolomite, Mg-Al-silicate, other silicates}. If a solution is at equilibrium with respect to these minerals, the Pco_2 value equals the product of their thermodynamic constants mainly dependent on temperature and independent of other characteristic such as chloride content : $Pco_2 = \Pi_j\ K_j^{-\alpha_j}$. The set of minerals including one carbonate fit the lower Pco_2 data from magmatic rocks. The one including two carbonates fit the higher Pco_2 data from sedimentary environments. These results allow to provide geochemical constrain when modelling evolution of chemical composition in aquifers.

GEOSTATISTICAL SIMULATION OF AN AQUIFER, CONDITIONED BY HEAD AND TRANSMISSIVITY MEASUREMENTS.

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Geostatistical conditional simulations are an approach of inverse problem, in the sense that they provide a family of transmissivity fields, consistent with the experimental hydraulic head and transmissivity measurements. Moreover, the geostatistical simulations reproduce the spatial variability of the transmissivity, as inferred on the variogram and experimental bivariate spatial distribution.
One apply here a approached method for conditioning the transmissivity simulations by the experimental values of head and transmissivity, using a linearization of the diffusivity equation for calculating the residuals of each variable. The covariances used for conditioning cokriging are calculated numerically, for taking into account the limit conditions and recharge.
The studied aquifer, sampled with 26 piezometers, can be modelised in 2 dimensions, and permanent flow. Boundary conditions and recharge values are given from the hydrogeologic study. 500conditional simulations are built.
The validity of the linearization in the conditioning step is controlled numerically.
The incertitude on the real value of the transmissivity is evaluated empirically on the 500 simulations : range of variation or standard deviation at each grid nod, histogram at some grid nods ...

CALCULATION OF HOMOGENIZED PARAMETERS FOR UPSCALING TRACER FLOW THROUGH HETEROGENEOUS MEDIA

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In this paper, we use the MHD approach that generalizes the traditional description of macrodispersivity for strongly heterogeneous fields. The MHD model permits us to describe the flow of a tracer using two parameters, H and D, which describe the heterogeneity. The parameter H characterizes the correlated heterogeneity leading to convective spreading of the invading fluid (spreading proportional to traveled distance x). Non-correlated heterogeneity that causes diffusive spreading of the front (spreading proportional to sqrt(x)) is characterized by the dispersivity D.
We then calculate the homogenized parameters <D> and <H> when a 2-D fine grid displacement is collapsed into 1-D containing N coarsened cells. Three approaches are studied: (1) When the MHD model is used, the homogenized parameters have the same value in all cells, and <D>=D, <H>=H, (2) When the advection-dispersion equation is used, <H>=1, and the pseudo-dispersivity <D> is a function of N and depends on the cell position (x), (3) When the fractional flow is assumed to be a function of concentration only (the method of characteristics approach), <D>=0 and <H> is also a function of N and x. The space dependence of <D> has been observed during tracer tests and simulations. The MHD model is the first to be able to predict this dependence.

IDENTIFICATION OF FLOW MODEL PARAMETERS AND SCALE CHANGES WITH THE DIFFERENTIAL SYSTEM METHOD

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The physical parameters of an aquifer (APP), e.g. transmissivity, usually vary along a smaller scale length than that of the aquifer model parameters (AMP). The APP scale length is determined by the hydrogeological structure, whereas the AMP scale length depends upon the density of the head and source measurement stations and upon the goals of the model. We consider two synthetic aquifers, the first with a smoothly varying transmissivity and the second one very heterogeneous at a given scale length L. For each aquifer we generate two different steady flow situations (heads) at the scale L. Then we identify the AMP at the same scale L with the Differential System method, using as data all the N heads thus generated and the value of transmissivity at one point only. Finally, we consider a model with a scale ($3L$) larger than the previous; we identify the AMP at this scale by using $N/9$ equally spaced ($3L$) head data. The consequent loss of information produces a regularisation of the AMP, neglectable in the almost homogeneous aquifer and quite apparent in the very heterogeneous aquifer. This regularization has to be expected and is essentially the result of the dilation of the scale length.

UPSCALING AND DOWNSCALING: TRAVELING UP AND DOWN THE SCALES LADDER

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Some times data is collected at a scale smaller than that of the blocks in the numerical model. Some times the opposite is true. The process of integrating data at a small scale into a single homogeneous values at a larger scale is called upscaling. The process of assigning values to the model grid blocks based on a single datum representative of some average value over a larger area is called downscaling. Whereas upscaling is more common than upscaling both are problems involving the identification of model parameters from data collected at a different scale. The naive approach of assigning the measured values to the model blocks disregarding the discrepancy of scales is still commonly used. However, in aquifers with mild heterogeneities, not accounting for the smoothing effects occuring while traveling up the scales ladder might result in severe prediction errors.
It has been finally recognized that upscaled and downscaled values are not intrinsic aquifer properties. The change of scale can be rigorously done only if the boundary conditions controling flow in the area of study are taken into account. And even when the boundary conditions are taken into account, the aim of the problem should influence the upscaled/downscaled values. For example, the upscaled conductivity that matches average flow in the aquifer does not have to be coincide with the one matching contaminat breakthrough times.

UNDERSTANDING THE DUAL-PERMEABILITY BEHAVIOUR OF FRACTURED CHALK USING THE EXAMPLE OF ATRAZINE CONTAMINATION AT A PUMPING STATION.

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The nature of flow and transport around a pumping station in North Wiltshire (UK) is analysed to obtain insight into factors affecting atrazine contamination. The apparent correlation between atrazine concentration and abstraction rate at the pumping well is discussed in terms of the dual-permeability behaviour of the chalk aquifer. This problem is tackled using a dual continuum numerical model in which integrated flow, transport and chemical processes are established for both continua, which are assumed to co-exist at all points in space. The parameters controlling the advective and diffusive mass transfers between the two continua are studied together with the classical hydrodynamic and chemical parameters that characterise the matrix and the fracture network properties using direct modelling procedures. Although the coupled processes are complex, it is possible to determine the order of magnitude of the inter-continuum transfer coefficients and to demonstrate how the apparent correlation between atrazine concentration and abstraction rate is acquired.

ESTIMATION OF AGRICULTURAL NITRATE LOAD TO AQUIFERS BY A ONE-DIMENSIONAL TRANSPORT MODEL

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Modern agriculture with high inputs of inorganic and organic fertilisers provides a risk of groundwater contamination by nitrates. Increased nitrate concentrations in aquifers and private wells have been detected in Finland at areas, where intensive agricultural practices are carried out. At important groundwater areas mitigation measures are needed to protect the groundwater quality. Mathematical transport models serve as a tool to e.g. estimate transport times to water intake areas. As an input to such models, information about nitrate load is needed. The estimation of these losses by sampling in the field is expensive and time-consuming and usually possible only within small, restricted study areas or in lysimeters. The one-dimensional SOIL-N nitrogen model is used here to estimate the potential load based on information about crops, soils and fertilisation levels. As a result of model calculations, mean nitrate leaching coefficients are produced to be used further for evaluating the overall risk of groundwater contamination, or at a local scale, to be used as input data to a groundwater model.

DOCUMENTED CONTAMINANT TRANSPORT RATES – THEIR USE TO REDUCE UNCERTAINTY AND IMPROVE MODEL PREDICTION

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Documented, rather than 'estimated' transport rates, should be required input to ground water management and wellhead protection programs. However, such data may not always be rigorously input to regional model aquifer scales. Uncertainly in applying 'point-source' data, the perceived 'high' cost of getting it and scaling factors are reasons its importance may have been overlooked. Failing, however, to include such 'reality' causes misleading technical bias commonly compounded by continued misapplication. Legislated controls have also largely failed to address differences in (colloid) particles and dissolved chemicals transport. Many management and well-intentioned protection strategies have relied on simple flow assumptions and 'rule-of-thumb' regional values to predict velocities and transport. Model sizes are frequently too large to be effective. Multiple tracer test results over distances up to 100m in three 'managed' and significant porous media aquifers in Switzerland suggest localized channels of 10m to 50 m width limited the injected fluorescent and colloidal tracer migration. Velocity, based on first detection, was between about 40m/d and 250m/d for both tracer types, about twice the velocity for peak particle concentrations. Uranine peaks were from 50 to 100 percent slower than colloid peaks. Neither regional nor site-specific geology nor hydrogeology identified, beforehand, these channels with their rapid migration potential. Perhaps equal effort should be taken to appropriately scale models to match the input specificity and to develop pertinent local protection and management strategies rather than focus on basin or catchment-size models whose scale may not adequately reflect heterogeneity in transport potential. The distinct tracer behavior is significant as input to models of contaminant transport scenarios.

A HERMENEUTIC APPROACH FOR SIMULATION OF UNSATURATED FLOW IN A HETEROGENEOUS FORMATION

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In the present study a set of different observations, ranging from soft qualitative knowledge to hard physical data, are used to develop a simple method for simulation of preferential flow in the unsaturated zone. By adopting concepts from hermeneutics we demonstrate that each individual data set only partially reveals what is essential in this particular flow problem. A combined interpretation of all the data sets gives an integrated flow model. In the next step each observation set must be interpreted in light of the integrated flow model. This induces new interpretations of the data which may gives rise to an updated flow model. If there are significant differences between the updated model and the previous one, a reinterpretation of individual data sets may be necessary. In this way the observations, the hydrological concepts and the mathematical formulation of the flow problem are closely connected to each other in the interpretation, the mathematical modelling and the simulation process. The challenge is to find parametric relations that interconnect the different data sets to a consistent model and which reproduces figures (eg. breakthrough curves) that we are able to evaluate against controlled field experiments. At this stage we have preliminary formulations of the problem and suggestions for further work.

CALIBRATION AND UPSCALING OF HYDRAULIC CHARACTERISTICS OF 3D FRACTURE NETWORKS IN CRYSTALLINE ROCK

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In this paper the properties of the average crystalline rock outside the deterministic fracture zones is studied by means of 3D stochastic fracture networks. The data from Romuvaara site in Finland is used as an example.
The statistical behavior of the model fracture network blocks is calibrated with data from in situ transient pumping tests by varying the parameters of the transmissivity distribution of the single fractures. Fixed interval data obtained systematically with different measurement scales is used in the calibration. The goodness of fit between the simulated and measured distributions is evaluated with bootstrapping methods.
With the calibrated models further simulations are carried out to study the equivalent continuum properties and resulting conductivity tensors of the medium. Based on the results, the applicability of the continuum versus discrete network presentation of the current data is discussed.

MULTIVARIANT MULTIFACIES GEOSTATISTICAL SIMULATION FOR HYDRAULIC CONDUCTIVITY

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We present a methodology to include typical field data (2 types of surface electrical geophysics data, well logs, head measurements and hydraulic field testing) into the geostatistical generation of conditional realizations for heterogeneous 3-D hydraulic conductivity (K_{SAT}) fields. The methodology is based upon developing covariance models between the collected data and a conceptual model of the hydrogeological framework (hydro-facies). Models are needed between the various geophysical measurement, between the hard lithological data and between those two data sets. K_{SAT} values calculated from well tests must be associated to the relevant formation. The number of hydro-facies is determined via semi-quantitative analysis of the available data. First, 3-D conditional indicator realizations for the hydrogeologic frameword are generated. Gaussian sequential simulation is used to generate conditional realizations for the K_{SAT} field within each model. A simple statistical analysis of contaminant transport simulations results based upon the generated realizations is presented. At the same time, the same 3-D conditional indicator realizations for the hydrofacies are used with the geometric means for K_{SAT} from the gaussian sequential simulations. The latter is analogous to an zonal inverse solution. A comparison of the contaminant transport realizations for the two methods is presented.

USING DISTRIBUTED WATER TABLE MEASUREMENTS TO CONSTRAIN MODEL PARAMETER AND SIMULATION UNCERTAINTY

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A uniquely extensive set of water table measurements were made at the Setern-bekken MINIFELT experimental catchment in Norway. These data have been simulated using the distributed model TOPMODEL which is able to represent, in a relatively simple manner, the main processes of runoff generation and groundwater dynamics in the catchment. Good simulations are obtained for catchment runoff and water levels, recorded on an hourly basis in a number of boreholes. Extensive instantaneous water table predictions are more approximate, due to the nature of the saturated zone model. Monte Carlo simulation shows that parameters established by calibration, using the observed data, should be regarded as being subject to uncertainty. A Bayesian approach is used to show how the parameter uncertainty changes as information from the different data sets (flows, borehole time series and extensive water table depths) is taken into account. Associated simulation uncertainty bounds are also shown for each variable, and the implications for changes to the model structure discussed.

USE OF WELL LOGS IN AN INVERSE NUMERICAL MODEL DURING THE INTERPRETATION OF A DOUBLE PUMPING TEST

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During the interpretation of a double pumping test using an inverse numerical model, vertical flow and natural gamma-ray logs were incorporated. This double pumping test consisted of two pumping tests at a same site but in different aquifers. During each test the drawdowns were observed at several distances in both aquifers and the adjacent aquitards. Both tests are simultaneously interpreted with an inverse numerical model. In this model the drawdowns were first calculated with an axi-symmetric numerical model. The sensitivities of the drawdowns, defined in the logarithmic space of the drawdowns and of the hydraulic parameters, were calculated with the perturbation method. The Newton method was used as minimization algorithm. In the first interpretation phase the vertical flow log was used to deduce the relative variation of hydraulic conductivity in the lower pumped layer. By combining these hydraulic conductivities in one group in which the relative variation stays unaltered, the number of identifiable parameters was limited. The relative variation of the hydraulic conductivities of the upper layers was derived from the natural gamma-ray log. By taking these relative variations into account during a second interpretation phase a larger number of hydraulic parameters was identified with a sufficiently small joint confidence region.

INVERSE PROBLEM AND UPSCALING: COMPARISON BETWEEN THE DS METHOD AND A CLASSICAL STATISTICAL ONE

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The resolution of an inverse problem with the Differential System method (DS) for the identification of transmissivity provides a very natural alternative way to deal with the upscaling problem. This approach takes into account not only geometrical property, but also piezometric head and source terms, i.e. information on the fluid flow. The parameter scale is fixed when the model scale is chosen and changing scale only means changing the number of local pressure measurements in the DS data. Moreover it is very cheap from the calculation-time point of view.
A comparison between a classical geostatistical technique and DS is developed for a synthetic, two dimensional, confined, isotropic aquifer in a steady state case. After evaluating the error on the identificated transmissivity, the piezometric heads and the fluid flows given by the different methods are compared for several boundary conditions and source terms configurations.

DETERMINATION OF GEOSTASTISTICAL PARAMETERS USING PUMPING TESTS DATA

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Using geostatistical models to describe sub surface heterogeneities is becoming more and more popular among the community of hydrologists and oil reservoir engineers. These models are useful to quantify uncertainties, and give also acorrect framework to identify local parameter values given large scale fluid flow data. In a lot of cases, the underlying global stochastic parameters such as the correlation length l_c, the variance $\sigma^2_{ln(k)}$ of the local physical parameters that govern fluid flow are not well known from laboratory data, which are too scarce to give confident values.
In the present work, we study how these geostatistical parameters describing the stochastic properties of heterogeneous permeability fields may be estimatedfrom pumping test results. These tests are shown to yield estimations of the equivalent permeability of reservoir zones with increasing sizes. Using a Bayesian approach, we derive the geostatistical parameters l_c and $\sigma^2_{ln(k)}$ from the maximization of the likelihood to honor the actual pumping test data. Synthetic numerical experiments show that a good agreement is observed between the input parameters and their estimation. Once these geostatistical parameters are known, we can proceed to a classical parameter estimation procedure to generate as many high resolution reservoir maps as desired.

IDENTIFICATION OF FLOW PARAMETERS FOR A REGIONAL MULTI-LAYERED AQUIFER WITH THE DIFFERENTIAL SYSTEM METHOD

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The Differential System Method (DSM) has been applied for the identification of flow parameters of a real world, multilayered (two aquifers connected by an aquitard) groundwater system. The data for the DSM - heads and sources for three independent steady flow situations - are the results of a forward model that simulates groundwater flow in a 3700-km²-wide alluvial plain in Northern Italy; this model was developed at Istituto di Idraulica Agraria of the University of Milan and validated comparing its results with experimental data (heads and recharge fluxes). First we have considered each aquifer separately, assuming the leakage terms to be known. We have used the three available sets of data pairwise to identify the transmissivity; those identified values, that are similar for the three pairs of sets of data, have been used as initial estimates of transmissivity over a wide region. The final results have been compared with the reference values used in the forward model and are satisfactory (relative error generally less than 50%) even where the flow conditions are not optimal for the application of the DSM. The simultaneous use of the three sets of data allows for the determination of both transmissivity and leakage coefficient, with errors generally less than 30%. The identified values of the leakage coefficient are not physically acceptable where the leakage is small in comparison with the source term.

A FILTRATIONAL MODEL PARAMETERS AND INTERPRETATION OF HYDRODYNAMIC, ACOUSTIC AND THERMAL MEASUREMENTS DATA.

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Many of the used at present parameters of the filtrational flows models such as the interhole space permeability, the liquid viscousity in stratum conditions, porousity and others could not be obtained at once by experiments every so often. Thus, the calculation of multiphase filtration has been a problem in many cases, especially with composite environments of fractured-porous type. The questions of model parameters identification under the performance of the various independent experiments like that non-stationary filtrational pressure waves, pressure restoring curves and debit falling curves techniques, acoustic investigations of the hydrodynamically sound emission and non-stationary dynamics of the thermal fields are discussed. A numerically calculus data of filtrational flows models and associated natural experiments results are given.

AN INVERSE METHOD FOR MODELING MECHANISMS AFFECTING GROUNDWATER QUALITY

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New concepts are presented for modeling mechanisms affecting groundwater quality. The calculation of transfer functions constitutes a viable and effective alternative to conceptual models by enabling the calculation of physically realistic models without any compulsive hypothesis. This approach is powerful enough to model complex interactions within a multimedia approach, thus enabling an actual description of hydrogeological phenomena. Algorithms developed in the framework of signal processing theory as well as regularization methods are available.
This new approach is used for improving the understanding of mechanisms affecting nitrate transport in the groundwater of a small catchment of Brittany (France) as well as the quantitative interpretation of flow, nitrate and sulfate fluxes in groundwater and in the river.
By using nitrate and sulfate fluxes, the unit hydrograph is separated into nitrate-contaminated and denitrified groundwater responses to rainfall, which enables an accurate assessment of the ability of the catchment for denitrification processes. Joint processing of piezometric heads and nitrate concentration in groundwater provides transfer functions for recharge and nitrate transport from the soil to the shallow aquifer.

INDICATOR KRIGING AND INDICATOR SIMULATION: TOOLS TO INTEGRATE SOFT INFORMATION INTO THE PARAMETER IDENTIFICATION PROCEDURE IN GROUNDWATER MODELING

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In general groundwater modelers have to face the problem of few hard data but many vague guesses of hydraulic conductivity (K). Earlier studies have shown that indicator soft kriging provides reasonable estimates of the spatial distribution of hydraulic conductivity based on both quantitative 'hard' measurements and qualitative 'soft' data, i.e. lithological description of aquifer material. Hard conductivity data from the interesting aquifer can be used to translate qualitative information into binary indicator vectors of the local probability distribution K at sampling points. Indicator soft kriging then produces estimates of the local probability functions of K, from which the local expectation and confidence limits, respectively, can be obtained. A check of these results can be performed using a groundwater model and comparing the modeled flow velocities to field observations.
The estimates of local probability functions of hydraulic conductivity can now be used to produce equal probable spatial realizations of K on a denser grid by indicator simulation processing hard and soft data simultaneously. These realizations will help to assess flow and transport characteristics of the actual aquifer, as well as possible extreme conditions. The paper will illustrate these ideas by means of an actual data-set taken from pleistocene glacio-fluvial deposits in North Germany.

ESTIMATING AND TESTING OF SOIL HYDROLOGIC PROPERTIES FOR THE SIMULATION OF THE WATER BALANCE IN A PLEISTOCENE CATCHMENT BY SOIL HYDROLOGICAL FIELD MEASUREMENTS

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Soil hydraulic properties for a 220 km^2 creek catchment in East Brandenburg, Germany, were both measured and estimated from a database using different pedo-transfer-procedures. They were regionalized by referencing for soil units of a medium-scale (1:25000) landscape map. To simulate the unsaturated soil water transport the hydrological simulation model MIKE SHE from the Danish Hydraulic Institute was used. A comparison between soil hydrological field measurements and simulation results was used for testing the soil data. There was a good agreement in the temporal water content dynamics between hydrological field measurements and simulations results. The measured as well estimated soil data for the simulations produced comparable results.

INFLUENCE OF GEOPHYSICALLY DETECTED HETEROGENEITIES IN ALLUVIAL DEPOSITS ON REGIONAL SCALE GROUNDWATER MODELS

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The quality of groundwater modelling is largely governed by the number and accuracy of the available information, in particular data on the spatial distribution of permeability.
First, we compare two regional FE models, both corresponding to the same real environment. Model 1 is based on a large number of actual indirect data collected with a newly developed geophysical technique (radiomagnetotellurics) and shows a highly varying but structured distribution of inferred permeability. Model 2 is based on a deliberately reduced number of data and leads to a less heterogeneous, but more classical, distribution of inferred permeability. In the later case, the medium is even considered as vertically homogeneous so it can be reduced from a 3D to an horizontal 2D model. Both models will simulate water flow and transport of a dissolved conservative tracer in saturated medium.
Secondly, while keeping constant a given level of heterogeneity (model 1), values of the hydrogeological parameters K, m and dispersivity will be changed.
The first set of runs will provide us with information on the influence of the density of geophysical measurements on modelling results; the second set, on the sensitivity of the model to the hydrogeological interpretation of geophysical data.

Continuous Model: An Extension of the Classic Two-Region Model

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The combined effects of nonlinear sorption, non equilibrium mass transfer and the distribution of sorption sites on the transport of organic contaminants has been examined in porous media containing aggregates of clay minerals. The major goal was to develope a general mathematical concept for describing deterministically the transport processes of solutes with different adsorption characteristics. Furthermore, a model was developed to describe and to identify the cause of nonlinear sorption and process kinetics. This continuous model represents an extension of the classic two-region model. The model was developed on the basis of the assumption that the pore depth diminishes continuously with the penetration depth into the particle. Interpolation methods are used for the functional depency of the pore cross-sectional area per unit column volume and the densities of the sorption sites per unit depth. The diffusion process is explicity modeled. Therefore, a relatively small number of parameters results for the presented model, in comparison to the discrete immobile region models with fully mixed zones as can be found in the literature. By employing continuous metering of pore depth and diffusion process in the pores, the differing effective resident times in the aggregates of clay minerals may be accounted for by using only one set of parameters. The presented model is able to describe simultaneously a whole set of breakthrough experiments with different flow rates by using the same set of parameters. Investigations and analyses for varying surface geometries were also carried out.

INFLUENCE OF PARAMETER ESTIMATION IN KRIGING: AN EXAMPLE OF APPLICATION

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The presentation deals with the analysis of the use of the combined maximum likelihood and second order approximated correction technique, recently proposed by Todini and Ferraresi (Journal of Hydrology 175 - 1996) to account for the uncertainty of variogram parameter estimation in Kriging. In this approach the variogram parameter estimates are no more considered as fixed values (as is conventionally done), but rather as realisations of random variables, the true values of which are aunknown. By means of a second-order Taylor expansion, an approximate expression for the Kriging estimatesa is obtained as a function of the parameter estimates; subsequently, by taking expectations, an approximation, both for the expected value of the Kriging estimates and for their variance is obtained: A maximum likelihood estimator for the parameters is also formulated, which allows for estimating the variance-covariance matrix of the parameters as the inverse of the Fisher information matrix. An application of the proposed technique is applied to data relevant to the piezometric elevation of an aquifer in the Emilia Romagna region.

SENSITIVITY ANALYSIS AND INVERSE PROBLEM FOR THE SUB-REGIONAL FLOW MODEL OF THE NEOGENE AQUIFER

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In this paper, we present the results of a sensitivity analysis applied to a sub-regional flow model of the Neogene aquifer in the Mol area (N-E Belgium). The sub-regional domain is first described and the hypotheses used in the groundwater model are presented. In the context of an uncertainty analysis of the waterflow in the Neogene aquifer, we compare the results of two approaches for the calculations of sensitivity coefficients: the variational method, recently applied by the authors for determining uncertain parameters and geometry in groundwater flow and a parameter estimation technique based on the Gauss-Marquardt-Levenberg method (PEST code). The initial guess about the values of the parameters is improved by solving an inverse problem which is based on the minimization of a sum of a least square expression of the output (hydraulic potential) and a penalty function. The solution obtained by this inverse problem is discussed and further improvements in the model are proposed. They concern mainly the type of boundary conditions on the upper surface of the domain and the hydraulic parameters of the considered sand layers forming the Neogene aquifer.

EXTENDING TO FINITE ELEMENT SCHEMES THE KALMAN FILTER BASED INVERSE PROBLEM SOLUTION

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The paper discusses the possibility of extending to Finite Element schemes, the Kalman Filter based solution to the Inverse Problem, recently proposed by Ferraresi and Todini for Integrated Finite Difference schemes (Journal of Hydrology 175 - 1996). The Inverse Problem relates to the estimation of parameters characterising the hydrodynamic behaviour of aquifers given their geometrical description, the piezometric field, the net infiltration (infiltration minus abstractions) and the boundary conditions. The proposed method, which falls in the class of Bayesian estimators, is based upon a Kalman Filtering formulation which optimally combines a priori parameter values with the information contained in the observations in order to obtain the a posteriori parameter estimates. Although an exact solution can be found for the general case of linear triangular Finite Elements, and possibly for a special Finite Element approach, which allows for the explicit preservation of the mass balance, the Contol Volume Finite Element approach, in the present work a direct extension of the results obtained with the Integrated Finite Difference schematization to Finite Element schemes will be presented as a sufficiently accurate approximated solution.

UNBIASED IDENTIFICATION OF NONLINEAR SORPTION CHARACTERISTICS BY SOIL COLUMN OUTFLOW EXPERIMENTS

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Accurate parametrizations of the interactions of reactive solutes with porous media constituents are necessary for reliable risk assessement studies and the development of efficient sanitation strategies. A wildly used technique for parameter estimation is the conduction of coulmn outflow experiments followed by nonlinear mathematical identification of reaction coefficients (inverse modeling). This procedure, however, bears a number of unsolved problems with respect to uniquenes and identifyability based on the requirement for available shape information(sorption isotherms, e.g. Freundlich, Langmuir, etc.). We present a new approach for the identification of nonlinear interaction parameters of column outflow experiments. The procedure is free of any a priori-assumptions on shape and curvature of the underlying interaction process. Employing experimental data sets on reactive solute breakthrough, possible applications of will be shown and its feetures will be discussed. Error analysis based on singular value decompostion of the sensitivity matrix allows qualification of the identified parameters.

USING WATER AND TRACER FLUX INFORMATION AT CANAL BOUNDARIES TO IMPROVE AQUIFER PARAMETER ESTIMATION: BISCAYNE AQUIFER, FLORIDA

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Inverse numerical modeling is becoming a widely used tool to estimate aquifer parameters. Using only piezometric head in groundwater model calibration often result in estimated parameters with low confidence. In this field study, two data sets were added to the parameter estimation procedure: measurements of groundwater seepage to canals, and chloride tracer concentrations in canal and groundwater.
The study site was the about 15 m thick carbonate Biscayne Aquifer of Southeast Florida. Hydraulic conductivities may exceed 0.1 m/s due to strongly developed secondary porosity. Groundwater flow in the Biscayne Aquifer is strongly linked to canal water levels which are controlled to meet flood control, water supply, and environmental objectives. A 2-layer inverse 3-D flow and transport model was set up to estimate parameters of hydraulic conductivity, specific yield, leakance between the layers, and canal bed conductance. The model was automatically calibrated on three types of data, individually and in different combinations: (1) groundwater head, (2) seepage between the aquifer and canals, and (3) canal and groundwater solute concentrations. Results indicate that the use of different types of data in inverse modeling can significantly improve the confidence in model parameters.

WATER ELECTRICAL CONDUCTIVITY-WATERFLOW AS A LOW COST MEAN TO DEFINE STORMFLOW COMPONENTS AND BASIN INITIAL SOIL WATER CONTENT.

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The evolution of the relationship between water Electrical Conductivity (EC) - and streamflow (Q) is described during about thirty events of successive stormflows having occured during the winter 89-90 in a small 32 ha basin in Belgian Lorraine. First, the relationship EC-Q during the rising part of the event differs from the falling part leading to the creation of a clockwise hysteresis when displayed in a XY graphic with EC in the Y axis and the discharge in the X axis. This phenomenon is already known. On the other hand, the fact that this hysteresis becomes anticlockwise after some successive events has not often been observed. This behavior is analysed. Measurements of groundwater depth in the bottom of the basin during these episodes reveal different zones supplying the river according to the period of the year. Temperatures of streamflow and groundwater are also used to reinforce our hypothesis about the origin of water supplying the streamflow. In the studied basin, the direction of the hysteresis and, in a less extent, its slope and its amplitude are original indicators of the soil water status of the basin, at least in initial phase of stormflow events. They permit to refute with certainty some hypotheses on the origin of water and to support some others. Up to now, these indicators provide some qualitative interpretations. But in environmental sciences as well as in hydrology, given the scarcity of information with regard to the studied system complexity, this kind of cheap and easy to use approach can not be disregarded. Researches on other sites and methodologies integrating this qualitative information type are recommended.

HSA1 Hydrology and the Earth's Crust

03 Reactive mass transport: experimental studies of chemical, colloidal and biological processes

Convener: Gouze, P.
Co-Convener: Schäfer, G.

COLLOIDAL MASS TRANSFER OF METAL IONS WITHIN POROUS MEDIA

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The fate of metal ions in the presence of naturally occurring colloidal matter within porous media (quarternary gravels, quarternary flysands) was studied using an artificial aquifer of 10 m length. Giving the opportunity of a complete control of the mass balance, a high time resolution and a nearly one-dimensional flow, these kinds of experiments are especially useful to fill the gap between bench-scale investigations and large scale field studies. The colloid concentration was 10^9 particles/L, mainly quartz and calcite. The aqueous solution, corresponding to natural groundwater, was enriched with heavy metal ions (Cr, Co, Cu, Ni) in plain solution up to 20 mg/L, thus simulating a contamination eg. with galvanic wastes. Under these conditions Ni and Cu were transported mainly in solution (>85 %), whereas for Cr and Ni, up to 50 % was transported on inorganic colloids. The colloidal fraction decreased with the distance from the insertion point as a result of filtration effects. A fast colloidal transport was not observed. Based on these results field experiments were launched within the Munich gravel plain. The flow distances ranged between 50 m and 200 m. Zn and Ni were used as metal ions, uranine and sulforhodamine B as fluorescent tracers. The time resolution of up to 30 min and a transversal resolution of up to 5 m gave ideal boundary conditions. We observed a retarded transport with up to 50 % of the metal ions associated to colloids and recovery rates far beyond 10 %. Again, the metal ions in solution and colloid associated showed a similar transport behaviour.

SURFACTANT FLOW BEHAVIOR IN POROUS MEDIUM

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Using surfactants for *in situ* remediation of oil-contaminated soils is a promising technique: this has been demonstrated by many lab results as well as site pilot tests. However, the surfactant solution needs to keep enough stability in order to avoid any loss of hydraulic conductivity during the treatment. In the specific conditions of our study, a plugging of the porous medium occurs, in which clay minerals, present in small amount, or precipitation of anionic surfactant, due to the presence of calcium ions, are not involved. The loss of surfactant solution injectability results from a time-dependent alteration of the solution.
Experiments indicate that the plugging happens after one or two days of surfactant infiltration through the porous matrix. A greater volume of surfactant solution can be infiltrated before the plugging if the solution has been recently prepared. This is assumed to result from the necessary time for the micelles to agglomerate and to form liquid crystals in the presence of divalent ions, especially calcium ions, contained in the water used for the preparation. These crystals, according to preliminary light-scattering measurements, have a size large enough to be retained by filtration, near the subsurface. So, this filtration appears to be the major factor responsible of the reduction of the hydraulic conductivity. Such a plugging, can be overcome by the use of solvents, *e.g.* light alcohols.

EXPERIMENTAL DETERMINATION OF PHYSICAL PARAMETERS FOR THE SIMULATION OF LEACHATE FLUX AND THE TRANSPORT OF NON-CONSERVATIVE, ORGANIC POLUENTS

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This research deals with the determination of physical parameters for the calibration of a numerical model used to simulate the leachate flux and the transport of non-conservative, organic poluents, in a landfill waste depository with leachate recirculation, in the presence of macropores. Initially, experimental works were performed in order to obtain physical data to characterize the water flow in the landfill waste depository, with the determination of the characteristic water retention and hydraulic conductivity curves. In a second stage, MACRO model was used to simulate the landfill response to real rainfall data. A critical analysis of the results was performed, taking into account the spatial variability of the physical, measured and simulated scales

IMPACT OF SORPTION HETEROGENEITY ON REACTIVE SOLUTE TRANSPORT

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In an integrated approach of field experiments, laboratory experiments and numerical simulations, the influence of physical and chemical aquifer heterogeneities on reactive solute transport was investigated. To characterize aquifer heterogeneities, 400 sediment samples were statistically and geostatistically analyzed. The mean variation of the hydraulic conductivity was twice as large as the variation of the nonlinear sediment sorption capacities. Both properties showed a slight negative correlation.
Stochastic transport modeling, including variable hydraulic conductivity and variable Freundlich n and k parameters, were performed to quantify the resulting prediction uncertainty. A moments analysis for the dissolved mass showed that heterogeneous nonlinear sorption has a larger impact on the plume spreading than on the mean displacement. On the long term however, the nonlinearity of the sorption process was more important than the observed spatial variation of the sorption parameters. Despite of the extensive data base of measured transport parameters, there was still an obvious discrepancy between the real and simulated plume. These discrepancies may be attributed to non equilibrium reaction parameters which are difficult to determine at laboratory scale for field scale transport.

THE STUDY OF SOLUTE MOVEMENT THROUGH ROCK USING POSITRON EMISSION TOMOGRAPHY

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Positron Emission Tomography (PET) is a non-destructive laboratory technique that allows the imaging of positron emitting isotopes within a porous rock mass and hence can provide significant information about the factors influencing transport. Techniques have been developed to evaluate PET in its application to the study of hydrogeological processes in the common aquifer forming rocks of the UK. A purpose built flow-rig has been built to ensure adequate experimental control exists during tracer testing of fractured and unfractured material. A series of laboratory experiments using Positron Emission Tomography have revealed the effects of rock properties upon flow and distribution of the tracers during transport. Conservative (copper-EDTA) and reactive (fluoride) radioactive tracers have been employed and clearly show the differences in the distribution between the non-retarded and retarded species in Triassic Sandstone. Similarly, the effects of sedimentary structure and lithology are revealed. In addition, an investigation has been made of flow in natural fractures within the Jurassic Limestone where it can be shown that aperture variation controls the flow and creates zones of transient storage. The latter are thought to contribute to the 'tailing' typically seen in tracer breakthrough curves performed on single fractures. To study colloidal transport, a radio-labeled copper colloid has also been developed.

REACTIVE MASS TRANSPORT WITH BIODEGRADATION : BATCH AND COLUMN TESTS

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The migration of biodegradable pollutant and microorganisms in aquifers is the result of the competition between solute transport and physicochemical interactions and degradation of the micropollutant. So it is necessary to test firstly interactions between each phase under carefully controled laboratory conditions.
Our study is focused on the phenyl mercuric acetate degraded by an aerobic strain of *Pseudomonas Fluorescens.*
Observations due to experiments in batch reactors give properties of reactions along the solid interfaces. Mechanisms of growth and degradation in variable environmental conditions (pollutant, nutriments and bacterial concentration, pH, temperature) were established. The reaction (adsorption, precipitation and complexation) at the interface between PMA and solids like oxyde, clay and sand, have been identified.
Using column test, the retardation factor gives access to the retention capacity of a sand towards pollutant and bacterial strain, as well as the ability of degradation under flow conditions. These tests also allowed to evaluate the effect on the breakthrought curves of a number of different environmental factors For this each factor is varied one by one, keeping the experimental set up constant.
It is a stage to test the effective cleanup of contaminated porous media by bacterial strain

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It is a stage to test the effective cleanup of contaminated porous media by bacterial strain

REDOX FRONT ADVANCE IN LOW PERMEABILITY MEDIA DURING INTERGLACIAL PERIODS

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Migration of oxidizing groundwater could adversely affect the ability of deep geological systems to limit radioelements releases to acceptable levels. Glaciation-deglaciation periods could enhance the presence of deep oxidizing water, thus jeopardizing stable chemical conditions of the repository over a long period. We assess the possibilities of such redox front migration to happen in a quantitative basis, with limited regional groundwater flow schemes. We consider that the consumption of oxidants below soils will be governed by the reactions between groundwater and minerals and that the ability of the media to buffer an oxidant intrusion, will be dominated by the presence of minerals containing iron(II). Among those minerals, we can remark the presence of chlorite, biotite, siderite and pyrite. The ability of clays containing Fe(II) to act as oxidant sinks has been pointed out by several authors. Our study approaches the problem under two perspectives: equilibrium approach, where groundwater reaches equilibrium with minerals capable of releasing Fe(II), and kinetical, where downward movement of redox front is continually under progress due to dissolution of mineral. Preliminary results show that while equlibirum approach is correct whenever groundwater residence times are sufficiently long, reactive transport provides more accurate results.

THE FLOW THROUGH RIVER BED SEDIMENT AND ITS CONSEQUENCE ON TRANSPORT AND CONCENTRATIONS

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The exchange in the river bed between groundwater and channel flow takes place in an intermediate layer called the hyporheic zone. The dynamics of these processes are controlled by the permeability of the river bed sediment, the river morphology, the variability of waterflow and also the biological activity. Another factor in this matter is the impact of sewage water and its significance on transport and storage of various solutes in the hypheic zone. Field Studies at the medium scaled River Lahn (Germany) show the coherence of hydraulic processes and analysed concentrations, like oxygen or compounds of nitrate. The studies include water tests, which are extracted simultaneously from different probes at various vertical levels in the river bed sediment. The distribution of probes takes into account the natural morphology structure of the river and the precense of a sewage outlet in the middle of the river section. The hydraulic investigations are mainly done by tracer injections upstream and measurements of vertical temperature gradients in the river bed sediment. The results show that concentrations and storage are dominated by the natural structure of the river and the temporal dynamics of waterflow.

EFFECTS OF BIOMASS GROWTH ON THE HYDRAULIC PROPERTIES OF GROUNDWATER AQUIFERS

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The influence of a growing biomass on the hydraulic properties of porous media was investigated in laboratory columns inoculated with bacteria. The feed solution contained only acetate and nitrate and the concentrations were measured at six sampling ports and in the outlet. Pressure and flow measurements were made in order to indirectly quantify the reduction in hydraulic conductivity (K) along the column. The degree of change in K was different for different sand types. A numerical code based on a coupled description of flow and multi-species reactive transport is used to explain and derive important parameters from single column experiments and to explain observed differences between multiple column experiments.

THE IMPACT OF SPECIATION, PARTITIONING AND SORPTION ON THE MIGRATION OF MULTIPLE FLUID PHASES IN THE SUBSURFACE

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Chemical processes such as speciation, partitioning and sorption may impact the migration of multiple fluid phases in the subsurface. These processes affect a system's interfacial tension and wettability, which, in turn, impact the capillary pressure relation-ship, an important parameter in multiphase flow. The impact of these chemical processes was examined in air-water-quartz and o-xylene-water-quartz systems, containing either octanoic acid or dodecylamine. In the systems containing octanoic acid, the relative concentrations of the anionic and neutral acid forms determined the interfacial tension and hence, the capillary pressure. In the air-water system, lowering the pH below octanoic acid's pKa of 4.8 converted more of the acid to the neutral form, resulting in a proportional decrease in the capillary pressure. In the o-xylene-water system the opposite was observed: lowering the pH below 4.8 increased the capillary pressure due to the partitioning of the neutral form into the o-xylene where its interfacial activity was reduced. In the systems containing dodecylamine, the additional process of sorption at the quartz surface was important. Because of its basic nature, lowering the pH below its pKb of 10 converted more of the compound to the cationic form. This form sorbed strongly to the quartz surface, resulting in a maximum contact angle of about 70 degrees and 150 degrees in the air-water and o-xylene-water systems, respec-tively. Thus, the sorption of dodecylamine was able to make the quartz surface hydro-phobic, with a correspondingly dramatic impact on the capillary pressure relationship.

COMPARATIVE BEHAVIOR OF BIOCOLLOID AND CHEMICAL MASS TRANSPORT IN HETEROGENEOUS POROUS MEDIA

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Carefully documented colloid/solute mass transport behavior can develop better predictive tools and understanding of particulate, particulate-assisted and dissolved constituent contaminant migration/reaction processes. Our initial objective was to compare flow path and mass transport rates of biocolloids and dissolved solutes in heterogeneous porous media. This was done with repeated measurements in a well-defined physical tank model (MARCEAUs). Five different biocolloids (Marine-H4, H6, H40, Non-marine-T7, Psf2 bacteriophages) were variably co-mingled with both salt and uranine thereby providing a uniform input signal. The 1m x 1m x 6m tank with three different-permeability sands arranged discretely in 1080 'boxes' (10cm x 10cm x 40cm) has scale and pore-size conditions similar to some current field sites. MARCEAU's advantage was a controllable gradient, temperature and chemistry. Salt, a 'conventional' tracer, was monitored on-line and continuously at 360 nodes and gave a base with which to compare colloid and uranine response. This was measured at six 'wells' in three of the tank's distinct transport fields. Results showed a remarkably similar salt and uranine transport that was consistent throughout the tank. Double peaks were clear evidence of multiple pathway contributions in the longer path, lower permeability areas. Biocolloid behavior differed. Marine phages were consistent and throughout with similar breakthrough time to salt in high permeability areas. The subdued second response suggested more mass reaction and selectivity in pathway routing. Results provide a base for comparative colloid/solute transport modeling and related reactive process studies.

BEHAVIOR OF DINITROPHENOL HERBICIDES IN ALLUVIAL SOIL BATCHES, COLUMNS AND LYSIMETER.

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The present study was conducted at three different scales (batch, column and lysimeter) with four nitroaromatic herbicides: 2, 4dinitrophenol (2,4DNP), DNOC, dinoseb and dinoterb). The goal of the study was to test the reliability of relevant parameters determined at a particular scale to simulate or predict chemical behavior at other scales. Sorption and degradation properties of four herbicides were determined in mono and multi-solute systems with both batch and column experiments. The low residence time of chemicals in soil columns leads to an underestimation of degradation parameters as compared to the batch results. Both type of parameters were used to simulate lysimeter experiments consisting in the annual application of a mixture of two herbicides and a tracer at the soil surface under natural conditions. The observed results were correctly predicted with batch determined parameters for a mobile chemical (2,4DNP). The fate of the more reactive herbicide (dinoseb) can not be predicted correctly with both set of parameters. This demonstrates that under natural conditions, important processes occur that are neglected at the batch or column scale. These processes were identified as rainfall variability and biodegradation processes which were largely influenced by competitive sorption and crossed toxicity.

DEVELOPMENT OF A REACTIVE TRACER FOR IRON OXID /HYDROXID QUANTIFICATION IN SEDIMENTS.

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Ferric iron is a potential electron acceptor for biochemical processes occuring in sediments. To quantifiy the oxidation capacity of soils it is necessary to measure the iron content. A chemical substance transported with groundwater as a tracer which is adsorbed on the iron surfaces could be used to quantify the reactive iron. The breakthrough curve of such a reactive tracer shows a typical deformation dependent on the iron content or to be precise the amount of –OH groups bound to ferric iron.

Experimental studies were performed in laboratory columns. Quartz sand was coated with α-FeOOH (Goethite). The columns were filled with quartz sand and goethite coated sand. Four tracers (NaBr, Na_2SO_4, Na_2MoO_4, Na_2HPO_4) were used in the experiments. Breakthrough curves were recorded on-line with a conductivity measurement. It could be shown that NaBr acts as a conservative tracer while the other tracers showed a characteristic sequence of high to low sorption from $Na_2HPO_4 > Na_2MoO_4 > Na_2SO_4$. The form of the breakthrough curves was strongly dependent on the iron content. The curves could not be modeled with an advection/dispersion model when the sorption proces was only described with a Langmuir isotherm. Theoretical considerations showed that a pH-dependent Langmuir isotherm must be used. In the near future the pH-dependency will be incorporated in the transport model.

EVIDENCE FOR SELF-ORGANIZATION DURING REACTIVE FLUID FLOW IN A POROUS MEDIUM

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When a reactive fluid circulates inside a porous medium, dissolution can occur, resulting in porosity and permeability modifications of the rock. The positive feedback between fluid flow and mineral dissolution may destabilize an initially planar dissolution front and lead to more complex morphologies such as karsts. This is due to the self-focusing of the fluid inside the regions where permeability is increased because of local dissolution. Our study is carried out with two objectives: 1) Evaluate experimentally this process at a decimeter scale, 2) Compare the experiment to a numerical model of water-rock interaction. The experiment consists of an analogous two-dimensional porous medium that allows for the dissolution of halite under an imposed fluid flow. The numerical code used solves the equations of reaction and transport in a porous medium, represented as a two-dimensional grid, and hence predicts the temporal evolution of the reaction front. Both experiment and numerical simulation indicate the development of a dissolution instability.
This reaction-transport instability shows that if a rock is homogeneous at a considered scale, self-organization patterns can emerge, and large initial non-uniformities (due to tectonic events or sedimentary features for example) are not required to create porosity variations and localized deformation in the upper crust.

PHYSICO-CHEMICAL MODELING OF WATER-SOLID INTERACTIONS IN TAILINGS OF NEPHELINE CONCENTRATE

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There was accomplished laboratory and computer experiments simulating the processes of leaching in tailings and formation of chemical composition of effluents. Laboratory experiment consist in studying kinetics and dynamics of dissolution of multi-mineral phase in flow reactor. Thermodynamic calculation was done with use of program <Selektor> based on method of Gibbs free energy minimization. Codes implemented in the program enable to consider water flow through mineral phase as megasystem consisting of interacting reservoirs. Mass transfer between them is characterized by appropriate rate constant. Each of the reservoirs can have arbitrary TP-conditions. Kinetic data obtained from dissolution experiments were used to determine the magnitude of rate constants of mass transport between the reservoirs. Results of the modeling enable to consider general model of water erosion in the tailings and define emission of toxic elements. Important processes controlling metal attenuation in surface and ground water draining the tailings is precipitation of chemical species. There is preferable precipitation of Al and Fe in the forms of Al(OH3) and Fe(OH3) respectively. New-formed solids of Al and Fe, precipitating on the mineral phase of the tailings, slow down the dissolution rates and adsorb trace elements, thus decreasing their concentrations.

Phosphorus leaching from sandy soils in dependence on hydrological conditions

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Phosphorus leaching from upper soil towards near surface groundwater may significantly contribute to eutrophication of surface waters. At a field site close to Berlin a soil- and groundwater monitoring program has been carried out for quantifying phosphorus losses from soil. Time averaged P-concentrations in the soil water show a marked vertical gradient decreasing with depth. Based on the concentration profile and on groundwater recharge P-losses can be estimated. However phosphorus leaching depends very much on hydrological conditions as it is shown by irrigation experiments. Water containing no P was applied to the field for simulating heavy rainfall. Not only phosphorus load but also P-concentration in the soil water increases during the experiments. From laboratory investigations it was found that P-sorption in these soils can be well described with Langmuir-isotherms and first order kinetics. The desorption kinetics of topsoil is faster than the sorption of subsoil. Hence in a certain range increasing percolation velocity may lead to higher P-concentrations in subsoil. For stationary flow this assumption is tested with a 1-d transport model. Further, with increasing percolation velocity colloidal transport may significantly contribute to phosphorus leaching as it is indicated by field results.

USING GIS AND AERIAL PHOTOGRAPHS TO DETERMINE THE WATER LEVELS DURING FLOOD

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To map water levels in case of large floods, it is proposed to manage by GIS the great number of information extracted from aerial photographs. Our method is developed in 3 points: 1) segmentation of the flood plain in sectors with acceptable mean water depth, based on geographical limits and size criteria. 2) determination of minimum and maximum depth for each sector, based on the emergence or not of natural objets (vegetation, dikes ...). 3) amelioration of the estimation of the water depths, using all observed hydraulic connections between sectors (cracked dikes, flows ...). This amelioration is done solving a constraint system linking the different water levels estimated in 2). Application concerns Herault River for the November 1994 flood, with aerial photographs taken 6 hours after the maximum of flood. Results give good determination about water levels, the lateral dynamic behaviour of flood (1,5 m of difference in levels between centre and edges of plain), and the impact of dikes. These results are obtained without introducing neither general hydraulic equation nor local head losses coefficient. The great number of fuzzy information, compensate for the low quality of each one.

INFLUENCE OF THE RATE OF CARBONATE SEDIMENTATION ON THE DECREASE OF PHOSPHORUS HEAVY METALS IN THE WATER OF LAKE SEVAN.

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Sedimentation of seston is of great importance as it contributes to self-purification of lake water through sedimentation of contaminants. In lakes, sedimentation, as a 'transportation system', may be accompanied by precipitation of phosphorus, heavy metals, other inorganic and organic compounds. The study of seston sedimentation and seston's biogenic compounds, particularly P and heavy metals is important to understand their role in the biotic matter turnover and their effect on water quality in lakes. The facts on seston sedimentation in the Lake Sevan and on the reason of its intensification were published earlier. The decrease of Sevan's surface by 18,5 m cause destabilization of the natural turnover. As a result of high phytoplankton productivity the rate of sedimentation of seston in lake increased. Intensive growth of CaCO3 crystals and precipitation of calcium carbonate led to the decrease of phosphorus concentration at more then one digit. In order to study the degree of co-precipitation of P with CaCO3, laboratory experiments were conducted in Sevan. The increasing rate of sedimentation of phytoplankton is promoted by the aggregation if algae, bacteria and CaCO3 crystals. High pH values irreversibly determine the fixing of phosphorus in bottom sediments.

DETERMINATION OF SORPTION PARAMETER FROM BREAKTHROUGH CURVES USING ASYMPTOTIC ANALYSIS

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We analysed the asymptotic behaviour of breakthrough curves (BTCs) obtained after a single pulse injection of a solute. For nonequilibrium transport, the concentration at a fixed position in time was found to decay like $\exp(-\beta t)$ where β depends on both the transport parameters and the parameters describing the nonequilibrium process. For the Freundlich sorption, the concentration at a fixed position decayed with $t^{-\alpha}$ with $\alpha = 1/(1-n)$. For all cases examined a good agreement between numerical calculations and the asymptotic analysis was found. The asymptotic analysis for Freundlich sorption was applied to BTCs measured in the lab and field. Good agreement was found between the n values obtained from column and field BTCs. Estimated n parameters from the BTCs differed from n values obtained in batch experiments. This difference may be attributed to the occurence of hysteretic effects in the sorption/desorption process. The results from the asymptotic analysis of nonequilibrium sorption provide also an alternative way to derive transport and sorption related parameters from BTCs by changing the water flux. The results from the asymptotic analysis can also be used in standard inverse modelling techniques to either obtain good initial guesses or to reduce the parameter space.

HSA1 Hydrology and the Earth's crust

04 Coastal aquifer dynamics and groundwater recharge

Convener: Candela, L.
Co-Convener: Munoz-Carpena, R.

EFFECT OF DIFFERENT VEGETATION TYPE COVER ON THE UNSATURATED FLOW PROFILES AND WATER BALANCES IN SEMI-ARID AREAS OF SPAIN

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In semiarid areas of Spain, vegetation suffer a large water deficit, which is one of the main factors to the present degradation of the Mediterranean landscape. Degraded shruplands are the dominant plant cover, in front of pinus or holm oaks forest. The plant cover plays a multiple role. It constitute a buffer from the kinetic energy of the rainfall before the water reaches the soil. It produce a new spatial distribution of rainfall due to the throughfall and the concentration at the base of the trunk as stemflow, that probably increase the infiltration rate. In contrast, a volume of water is lost by interception by the plant cover, and plants are a water consumer in proportion to their biomass and type of plant community. With the aims of the vegetation management to improve the aquifers recharge in semiarid areas, we measure water content at three depths in 60 soil profiles (TDR method), to analyse the soil water infiltration after rainfall events, and the water uptake by plants, under 4 vegetation types and a bare soil (3 replicates): afforested pinus forest with shrubs, pinus trees without shrubs, shrublands without pinus trees, and dry grasses of Brachypodium retusum. Preliminary results shows that small rainfall (<10 mm) are intercepted by the plant cover in 40-70 %, having small effect on soil recharge, and any contribution to the aquifer. When precipitation is higher, throughfall and stemflow represent 80-90 % of rainfall, and their contribution to the unsaturated soil and aquifer recharge is positive. After rainfall, water content is high and similar in the upper soil level (0-10 cm) under all vegetation types, but in depth (20-50 cm) shrubs cover present the higher values. Seven days after, the soil water content indicate that the presence of grasses reduce water in surface (0-10 cm) but not in depth (20-50cm). In contrast, the shrub plants reduce in the low level (20-50 cm) more than the grasses and pinus trees.

INVESTIGATION OF AQUIFER BOUNDARIES AND SEAWATER INTRUSION IN THE COASTAL PLAIN OF THE PO DELTA USING GEOELECTRIC MEASUREMENTS

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ABSTRACT

Groundwater of coastal aquifers is usually vulnerable to quality deterioration due to saltwater intrusion(s). Under this context, a large scale geoelectrical survey, including some 100 VES, was carried out in the south-eastern part of the PO delta, Italy. These were integrated by a number of closely spaced (50 m - 150 m) soundings conducted along a profile oriented perpendicularly to the coastline. Moreover, an Induced Polarisation sounding and profiling test was also performed in two selected sites to investigate the depth to the bottom of the saline groundwater intrusion. The purpose of the investigation was to evaluate the subsurface geo-hydrogeological properties of the delta aquifers with emphasis on the saltwater intrusion problem.

HYDROGEOCHEMISTRY AND FLOW MODELLING OF THE AVEIRO MULTILAYER CRETACEOUS AQUIFER

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The Aveiro Cretaceous coastal aquifer is located in north-western Portugal, covering an area of 600 km^2 in the Portuguese Occidental Meso-Cenozoic sedimentary basin. The region is one of the most industrialised areas in Portugal presenting also a high demographic density.
The Aveiro coastal aquifer constitutes an important water resource for the region, guaranteeing most of the urban and industrial water supply since the sixties. In recent years a continuous fall in the water table has been observed due to intensive groundwater abstraction, leading in some areas to values of –25 m below m.s.l.. This fact because it occurs in a coastal aquifer, partially confined and with a limited natural recharge, can lead to deterioration of the water quality either because of salt water intrusion phenomenas or due to mixing with very high mineralised waters from deeper aquifer levels, nowadays with higher water potentials.
Being a vital resource for the region, the Aveiro aquifer acquires a certain economic value, which makes important the adequate evaluation, exploitation, management and conservation of its resources.
Detailed hydrochemistry studies, including the analysis of major, minor and trace elements, and groundwater modelling are being used for a better understanding of the aquifer behaviour and as a scientific tool for groundwater management.

CURRENT ISSUES IN COASTAL AQUIFER DYNAMICS AND GROUNDWATER RECHARGE

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Coastal aquifers provide important groundwater resources and contain key emergency freshwater reserves usable during droughts and as back-up of other water supply systems, both in rural and urban environments. Principles governing fresh and saltwater relationships and dynamics and how they mix are well known. But actual behaviour depend on the ability to adequately describe local aquifer properties. Intensive groundwater development is possible but it may lead to early well salinization problems through preferential paths such as coarse layers or large fissures. Also unflushed old marine water is a source of salinization which may represent transient situations of long residence time parts of a system. Early warning systems, monitoring means and adequate water abstraction pattern reduce riks and help in controlling unwanted salinization. 3-D simulation es currently possible although complex situations may become unfeasible due to limited computer capability. Reliable calculation of aquifer recharge from rainfall and climate data is still a major hydrogeological challenge. It is possible to obtain acceptable values of its time distribution by using apropriate calculation codes calibrated against groundwater levels and/or spring/river discharge, and checked by means of solute balances, mainly chloride and water content changes in the unsaturated zone. The main remaining problem is the need for some non-physically based parametres for which there are no previous estimates, or complex aquifer response to recharge events.

COMPARISON OF DIFFERENT TRACER METHODS TO ASSESS NATURAL RECHARGE IN COASTAL AQUIFERS

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Groundwater resources in coastal aquifers may be threatened due to their scarcity and over-use. Therefore, natural recharge becomes a critical issue since it is the main source term in the absence of processes induced artificially. Different techniques are needed to asses natural recharge acording to local characteristics. In addition, different methods applied to the same aquifer may display conspicuous differences. Tracer experiments in the vadose zone have several advantages to evaluate recharge yet they directly reflect the on-site processes (they are direct), are sensitive to direct evaporation and are affected by transpiration when vegetation is present. On the counterÓrt, tracers may be selectively affected by physical or chemical soil processes and be uptaken by plants, and the results may be biassed by the measuring devices. This discussion was applied to two experiments in coastal aquifers of detrital nature: a small narrow strip under intensive agricultural practices and an extensive deltaic area. Different methods applied are compared. The validity of traditionally conservative tracers is discussed. Multiple mass balances permitted to discern the different terms involved in the recharge process.

MODIFICATIONS IN A COASTAL AQUIFER INDUCED BY CHANGES IN WATER MANAGEMENT UPSTREAM (ADRA RIVER DELTA, SE SPAIN)

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The Adra river basin (SE Spain) extends over the southern slopes of the Sierra Nevada massif (peaks near 3000 m) in an area of semiarid climate. Snowmelting from the head sector provides most of the runoff with associated low mineralized waters. In its middle reach the river crosses a triassic carbonate aquifer that also contains evaporite materials. Important losses from the stream water to this aquifer were reported through this reach. Downstream, the river is a gaining course in relation to the carbonate aquifer: Fuentes de Marbella springs (FMS) discharge sector with moderately brackish waters. In its lower reach, the river runs over -and recharges- the Adra delta aquifer which is irrigated from streamwater and pumping wells. The beginning of the operation, in 1982, of the Beninar dam located a few kilometers upstream from the FMS has induced the leakage from sinkholes within the reservoir, increasing the outflow of FMS, specially as a consequence of the important precipitations of late 1989 and 1995. Related to this process, the deltaic aquifer has modified both the seasonal pattern and the magnitude of its piezometry. Furthermore, the chemical quality of the groundwater tends to approach that of FMS.

PROBLEMS ASSOCIATED WITH MODELLING SEA WATER INTRUSION AT LARGE SPACE AND TIME SCALES

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Encroachment and retreat of the sea at geological time scales exert a dominant control on the evolution of fresh and salt groundwater in coastal areas. We investigate to what extent these processes can be properly represented by the variable density finite element groundwater code METROPOL-3. Special attention is being paid to convective flow instabilities which can arise when transgression of the sea carries sea water on top of fresh ground water. It will be shown that the dimensions and temporal development of finger instabilities can be adequately simulated, but require grid dimensions of the order of 10^{-2}-10^{0} m for realistic aquifer permeabilities. For coarser grids - required for large-scale problems - finger dimensions are controlled by the grid rather than the boundary layer Rayleigh number. The influence of the grid on spatially-averaged aquifer salinisation will be discussed

WATER MANAGEMENT IN A SOUTHERN COASTAL REGION OF SPAIN (THE VÉLEZ RIVER). SIMULATION OF GROUNDWATER AND SURFACE WATER FLOW FOR THE PROPER FRESHWATER BUDGET

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The hidrological regime of the detritical aquifer of the Vélez River (Málaga, Spain) has been substantially modified since the La Viñuela reservoir system started operating in 1989. Its setting up in the higher basin has caused a decreased of the aquifer recharge. In addition, the persistent drought in the first half of the 1990s and the increasing exploitation of aquifer resources have produced a considerable drawdown of piezometric levels, accompanied by groundwater quality deterioration and seawater intrusion. Irrigation with treated municipal wastewater in the coastal area has been considered as a water management alternative in order to reduce groundwater exploitation by pumping wells and saltwater intrusion from the sea. A finite element numerical model is used to carry out steady state simulations of water flow in both groundwater and surface water with the help of open boundaries for the proper freshwater budget. Annual mean volumes of recharge (30 hm^3/yr), reduced exploitation (-29 hm^3/yr), wastewater irrigation return (0,3 hm^3/yr), irrigation return (1,4 hm^3/yr) and net rainfall (1,7 hm^3/yr) were considered in the whole catchment-basin of the studied system. The accomplished simulation provide a decrease of seawater intrusion in the coastal sector as a result of this water management alternative to a clearly positive value (4,4 hm^3/yr) of freshwater discharge to the sea.

Assessing groundwater exploitation in the Alt Emporda coastal aquifer.

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Groundwater exploitation in the Alt Emporda coastal aquifer (NE Spain) was stopped in 1985, after two decades of intense withdrawal, specially in the summer season. At that time, chloride concentration was above 1500 mg/L, being not suitable for domestic uses. Presently, water supply depends on surface water only, which may be insufficient in extremely dry years. Therefore, groundwater resources must be added to fulfill the local demand. To assess aquifer exploitation, we have investigated the maximum discharge rate that will kept chloride at suitable concentrations. Hydrological and chemical data indicate that chloride was leached from the confining layers to the main sandy aquifer. A mathematical model based on Hantush and Jacob (1955) equation for leaky aquifers, considering variable discharge in multiple wells, is used to estimate the flow from the aquitard, and therefore the amount of salt leached to the aquifer. Simulated data are calibrated with the chloride monthly record from 1975-82. Finally, we present the feasibility of completing the water demand in dry years with high quality groundwater (Project CICYT AMB95-0867).

CHEMICAL EVIDENCE OF SURFACE WATER INFILTRATION IN THE CASTELLON PLAIN AQUIFER, SPAIN

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Mijares river pass through the Castellon Plain (middle east of Spain), a coastal detrital aquifer heavily affected by agricultural pollution reaching up to 400 mg l^{-1} of nitrate. However, low contents of nitrate have been found in a linear sector along the Mijares river. Mijares river is basically regulated by the Sichar dam before passing through the plain, but other small dams exist downstream. There is some evidences of water infiltration at the Sichar dam itself (more that 20 hm^3/year) being one of the main mechanisms recharging the plioquaternary aquifer. Preferential flow along the subaluvial materials could partially explain the presence of the freshest and less polluted water in a narrow fringe from the border up to the coastline, but some located areas show specific hydrochemical characteristics. These areas are in coincidence with the small dams. Hydrochemical studies have been carried out in order to establish some type of relationship between the water infiltration and groundwater quality. The results show a high coincidence of chemical parameters of both surface and groundwater, and a closed relation has been found in the trends of both water types. In the other hand, variations of the hydraulic head are closely related with storage conditions in the dams. In conclusion, the located high quality groundwater in the Castellon Plain aquifer is related with preferential surface water infiltration.

SEAWATER INTRUSION AND SALINE REGIONAL WATERS. A SYNERGIC SALINIZATION

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Water in the south area of the Castellon Plain aquifer (middle east of Spain) is of a calcium-magnessium chloride-sulphate type, with high contents of strontium and lithium. Both direct seawater intrusion and a notable addition of sulphatic water contribute to the final chemical quality in the area. Seawater intrusion affects to the plioquaternary aquifer due to overexploitation. Sulphatic waters may originate from a heavy withdrawal directly from the deep aquifer related to the presence of structural heights in the mesozoic substratum (triassic dolomies). Overexploitation in the area therefore causes two concomitant facts, the reciprocal prevalence of which may depend on the permeability of plioquaternary aquifer along the coast. Where high permeability occurs, overexploitation causes lateral seawater intrusion ; and where permeability, and therefore contact with the sea, is reduced, overexploitation causes the downward withdrawal of sulphate waters. Even without piezometric measurements of the deepest aquifer, it can be seen that with moderate water use the hydraulic head of the plioquaternary aquifer dominates that of the deep system, whereas with overexploitation, the hydraulic head of the deep aquifer prevails over the depressurised shallow aquifer. Distribution of sulphate, magnessium, strontium and lithium ions are good tracers to differentiate the effect of each saline process.

THE GROUNDWATER RECHARGE IN THE AZUL AQUIFER, CENTRAL BUENOS AIRES PROVINCE, ARGENTINA

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The potential evapotranspiration using Thornthwaite equation (1948) followed by a monthly water budget of teh soil according to Thornthwaite-Matter (1957) are currently employed in Argentina for estimating the groundwater recharge due, mainly, to their low-data requirement. If such a budget is carried out in the central region of Buenos-Aires Province, where the Azul aquifer is located, a recharge of 10-15% of the annual rainfal is obtained, which is about 900 mm. Such a region in a plain where most of the primary agricultural activities are carried out. Recently, the application of other methodologies have came up with sustantially higher values for evapotranspiration and lower values for groundwater recharge. Such methodologies are the estimation of the areal real evapotranspiration coming out from the Morton's model (Morton et al., 1985), the mass-balance of chloride, and the groundwater-flow simulation using the recharge as the calibration parameter. In all cases, a mean annual recharge of 40 mm is obtained, with some details given by the groundwater model which discriminates two sectors with recharges of 52 and 16 mm/year associated to soils of different types and uses. Hence, this paper attempts to demonstrate that the Thornthwaite method severily overestimates the groundwater recharge, thereby hindering the possibility of using such estimates in long-term planning and management of the water resources.

HSA2 Hydrology and landforms and fluvial systems

01 Measurement of bedload and suspended sediment in turbulent flow

Convener: Laronne, J.B.
Co-Convener: Ergenzinger, P.

BEDLOAD PULSES ASSOCIATED WITH MIGRATION OF SAND DUNES

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Series of bedload measurements are underway in the perennial Arbúcies river (Catalan Coastal Ranges) to characterise the relation between short-term bedload pulses and migration of bedforms. Hand-held Helley-Smith samplers are used under steady conditions, from low flows to bankfull discharges. In order to provide information about fluctuations in bedload rates, sampling time is as short as possible and defined with respect to the pass of a primary dune through the sampling section. Flow depth and velocity, bedload size distribution and suspended sediment are also monitored. During first set of measurements mean bedload was 392 gr m^{-1} s^{-1}. Ratio bedload-discharge to water-discharge (ib/Q) was 1/500. Coefficient of variation reached 50% and maximum variation 800% at two minutes interval. Median bedload size varied from 4 to 6 mm. During second serie, mean bedload rate was 67 gr m^{-1} s^{-1}, (ib/Q=1/3000). Coefficient of variation performed high at 40%. Maximum variation between consecutive samples reached 225%. Median bedload size was 1 mm in the channel centre and 0.7 mm near the banks. Movement of sand is clearly dependent on bedform migration; maximum rates occur over the dune's crest and minimum bedload takes place during the elapse between two dunes. Variability between samples is higher under higher water and bedload discharges. This fact indicates that increasing passage of dunes not only increases bedload rates but also the variability between them. In addition, bed-material size increases substantially with bedload rates.

CONTINUOUS MONITORING OF BEDLOAD DISCHARGE IN AN EXTREME ARID ENVIRONMENT, NAHAL RAHAF AND KANAIM, DEAD SEA, ISRAEL.

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We shall present the first-ever published record of bedload flux continuously monitored in an ephemeral channel located within an extreme arid environment. The site is the often braided Nahal Rahaf and its mountainous, narrower and steeper, cobbly-bouldery tributary Nahal Kanaim. They drain to the Southern Dead Sea near Massada. The station was installed 2 years ago after which the sections regained equilibrium above the trap sites. This winter has continued to yield high quality data as follows: bedload flux within an anabranch (inner channel) and another on a bar on the Rahaf, and a centre-channel slot on the Kanaim; additionally, we monitor water surface slope in the Rahaf at higher flow stages, and water stage at all water stages. We have recently installed a continuously monitoring turbidity sensor that is operable and calibrated to as much as 80, 000 ppm. We have sampled suspended sediment concentrations of 3-5 percent. Because of the steep slope and the limitless availability of sediment (both fine grained and coarser), bedload fluxes are very high. Discharges exceeding 10 kg /sm have been monitored. Although these are very high, bedload concentration does not exceed ca 5 percent of total sediment concentration. This has also been ascertained independently from Nahal Rahaf reservoir resurveys. Bedload - shear stress relations are presently being analysed. They demonstrate the high availability of bedload in this environment. The very fast accumulation of bedload inside the traps has brought forwards a multitude of technical problems in the datafiles as well as in their analysis.

EFFECTS OF THE 3-D TURBULENT FLOW FIELD ON TRAP MEASUREMENTS

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During the past 20 years several slot-type trap devices have been developed to continuously measure bedload transport. This paper deals with the effects of the turbulent flow field on the trap measurements. The prototype measuring system at the Drau River, Austria, is a slot sampler consisting of a fixed concrete tube of 2 m diameter and 1.5 m depth and two steel boxes, one located inside the other. The boxes can be taken out and reinserted into the concrete tube. In order to achieve a reasonable hydraulic efficiency, two boundary conditions have to be met. First, the slot should not significantly influence the flow field outside the trap. Second, flow velocities and turbulent structures inside the trap should be minimal in order to prevent remobilization of trapped bedload. Using 3-D flow velocity measurements with an electromagnetic current meter we demonstrate that the trap does not influence the 3-D turbulent flow field outside the trap. The flow field within the box depends on the extent of trap fill. On top of the sediments the flow velocities reach values less than 10 mm s^{-1} with relations between x / y and x / z directions of less than 7 and 40. Up to a stage of 80 percent fill the hydraulic conditions inside the trap are those of an essentially standing body of water, similar to those encountered in the prototype measurements when the trap is empty and when its hydraulic efficiency is almost unity.

QUANTITATIVE EVALUATION OF BED LOAD MEASUREMENTS IN THE RIVER RHINE

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The river Rhine is the most important waterway in Europe. In the last 200 years it was straightened leading to considerable changes in the morphological dynamics (deepening of the river bed). In order to observe and regulate this process, bed load measurements are carried out by the Federal Institute of Hydrology since the beginning of the 70ies. Measurement sites are located in the average every 15 km.
The large scale sediment budget is calculated based on the relation between discharge and sediment transport. The shape of the transport/discharge-function cannot be clearly determined due to the high scatter of the measured data. Therefore different functions are set up. The deviations between measured and calculated loads are assessed using a cross-validation approach. This can be used both for the comparison of different transport formulas and for the detection of possible outliers of the measurements.
The uncertainty of annual sediment loads cannot be quantified by common statistical means. Therefore a bootstrap method is used to assess quantitatively the uncertainty of long term loads (confidence intervals, variation coefficient, ...). So each measurement cross section can be judged and the measurement strategy can be optimized.
Furthermore, the possible transfer of information of nearby measurement locations is under investigation using Bayesian statistics.

Influence of ring structures and shear stress distribution on river bed stability

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In a torrential river water, depth and slope of the river bed are very variable parameters owing to rapid fluctuations of discharge and sediment tranport. Therefore it is not possible to characterize the shear stress of the river bed by a mean parameter. In order to understand more about stable bedforms and structures on the surface of the river bed, it is important to obtain a more precise knowledge of shear stress distributions and the interactions between turbulences, shear stresses and ring structures.
Stability problems of ring structures and the validity of the mean shear stress are discussed. Proposed results are based on actual measurements at a test site in a mountain torrent with varying discharge, as well as on flume data. The stability of ring structures can be defined with these data so that a physical explanation is possible. The results of the study demonstrate the importance of a more precise description of active shear stress in a mountain torrent using the proposed distribution function.

VELOCITY FIELD AND RESISTANCE OF FLOW OVER ROUGH SURFACES WITH LARGE AND SMALL RELATIVE SUBMERGENCE

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In gravel bed rivers surface, form and system roughness changes with time due to grain sorting. In the course of this armouring the roughness of the river bed as well as the bed resistance increase till a stage of so-called maximum bed stability is approached. Thus, to estimate the stability of these river beds the precise knowledge of the velocity field and the corresponding resistance of the flow over rough surfaces are of great importance.
In this study, important formulas that describe the flow field over rough surfaces with different relative submergence are summarized and explained. It turns out that the flow field over rough surfaces with small relative submergence deviates remarkably from the one with large relative submergence. Differences in flow resistance as well as velocity and turbulence intensity distribution are documented with own data and data from the literature. The consistency and inconsistency in the results of velocity and turbulence intensity distribution as well as flow resistance are pointed out and discussed. Finally, physically based explanations are given for the deviations of the results.

'Bursts and Cyclical Movement of Sand/Granules on Mobile Bed Patches Utilising Video Photography -the Tordera River'

Jonathan Laronne and Celso Garcia

This talk will focus on the character of initiation of motion and actual transport paths taken by individual sedimentary grains in mobile bed patches. Examples will be given from video runs of patches in the bed of the Tordera River.
It is apparent that bedload transport takes the form of bursts and cyclical movement within patches. Most of the particles move in saltation and rolling - few slide. During time intervals longer than the bursts, some of the sediment moving internally within the patch spills downstream and out of the patch. The location of the spill is rather constant and depends on the geometry of the patch boundary, particularly in the lee side. Additionally, it appears that the character of the secondary ciculation within the patch is controlled to a large extent by the size, shape and location of the protruding clasts located mostly in the stoss of the patch.
The presently acceptable description of gravel bed topography as comprising mostly pockets between and protrusions of patrticles is a simplification that may considerably undermine the validity of presently available deterministic models of bedload transport. Defining the mechanisms of bedload movement within and out of mobile bed patches may be very useful in the outline of such models of real gravel bed rivers. It may be particularly relevant to models of initiation of motion and in evaluating bedload flux during conditions prior to pavement disruption.

ASSESSMENT OF MOUNTAIN STREAM ANNUAL BEDLOAD TRANSPORT RATES IN THE DROME WATERSHED, FRANCE.

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The aim of this study is to assess annual bedload transport rates of mountain tributaries of the Drôme river which drains the southern prealpine range of the Diois (Rhône basin, southeastern France). We have selected 3 mountain streams in the upper part of the Drôme basin. These are characterized by channel narrowing processes associated with bed degradation in their lower reaches induced by coarse sediment supply decrease from hillslopes. Vegetation development in channels is more pronounced in the Barnavette creek (inactive torrent) than on the Esconavette and Beous ones (active torrents). Annual bedload transport rates have been measured using a technique which associates scour chains, painted particles and surveyed cross sections. This paper presents the first results of an investigation which has started in the beginning of 1997. The accuracy of measurements is less than 5 % on the Esconavette creek in comparison with the surveying of a mining hole filling. This torrent has transported 372 m^3 of annual bedload for a total mean cumulative distance of 230 m on the occasion of 5 flow events of less than one year interval recurrence. Annual bedload transport rate and annual distance of transport on the Barnavette creek has been evaluated at 520 m^3 and 270 m (5 flow events with a major flood occuring on July). On the Beous creek, we measured 2 minor flow events which have mobilised 260 m^3 of bedload for a total distance of 200 m. Bivariate relation between peakflow discharges and bedload transport indicates a high variability between the 3 torrents when discharges are greater than 10 $m^3\ s^{-1}$. This can be attributed to the different sediment availability according to torrent activity.

PREDICTING BEDLOAD FLUX UNDER WAVES

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To determine the effect of turbulence on sediment transport, we used high-speed cinematography and laser-Doppler velocimetry to measure bedload flux and near-bed velocity at 100 Hz in an oscillatory flow in the lab. A constant value of stress was found to yield significantly different flux depending on phase of the wave. On the accelerating limb, turbulence and vertical momentum exchange tend to be reduced, so mean velocity near the bed increases without much increase in the standard deviation of velocity. In contrast, deceleration produces an increase in turbulence and standard deviation of velocity. Because sediment transport depends on the highest velocities (including turbulent fluctuations) that occur near the bed—rather than "average" conditions—flux is enhanced during the decelerating limb of a wave. Even experimental waves vary from each other, and such variations make it difficult to predict the actual time series of flux through differing individual waves. Nonlinear input-output modeling was used to relate time-varying sediment flux to velocity; the correlation coefficient between flux and velocity was weak ($r^2 = 0.05$). Smoothing the data to 4 Hz improved the correlation between flux and velocity ($r^2 = 0.37$). Additional increases in accuracy of predicted flux time series were achieved by basing predictions on turbulence in addition to velocity ($r^2 = 0.52$) and by using 3-second sequences of velocity and turbulence to characterize the flow ($r^2 = 0.79$).

HSA2 Hydrology and landforms and fluvial systems

02 Morphological processes at the hillslope and river scale

Convener: Roth, G.
Co-Convener: Copertino, V.

CLIMATE CHANGE AND FLUVIAL DYNAMICS: A MULTI-MODEL APPROACH

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The adjustment of alluvial rivers to external forcing is characterised by a complex response. Research on the river Meuse (Maas) has shown that it's morphological response to the LateGlacial – Holocene transition consists of alternating phases of incision and deposition as well as changes in channel planform type. On basis of these observations, hypotheses regarding the response of river systems to climate change in general were proposed.
A quantitative model for medium to long-term river dynamics is being built. The main targets of this model are testing of these hypotheses and quantification of total sediment throughflow. This model is based on an integration of existing knowledge of fluvial dynamics. This knowledge consists of detailed process descriptions as well as empirical relationships between equilibrium values of fluvial system variables. For example, detailed numerical models of meander evolution or braiding dynamics are available from which heuristics regarding meander belt width, braiding index etc. can be extracted and used in a general model. Many empirical relationships are bases on limited datasets and require careful assessment before they can be applied in a general model.
The model under construction will therefore be based on a combination of various sub-models. A number of these will be discussed, and some preliminary results will be presented.

ON THE DISTRIBUTION FUNCTIONS OF THE PEAK AND THE TIME TO PEAK OF TOPOLOGICAL WIDTH FUNCTION

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Since the introduction of the geomorphological instantaneous unit hydrograph in hydrology (*Rodriguez-Iturbe and Valdès*, 1979), a number of analyses has been devoted to establish the extent to which the network structure can be used for determining the hydrologic response of a basin. Particularly, the so-called "width function formulation of GIUH" is based on the analysis of the statistical properties of the width function, which denotes the number of drainage areas sharing the same distance x from the basin outlet. Referring to those drainage basins where link lengths and link-associated drainage areas are constant, an ideal network could be defined, in which the overall structure differs from the topological one on a length scale only. Under this simplified arrangement, the drainage area of any link is proportional to the magnitude of that link, and the distance from the outlet is proportional to the bifurcation level. In the paper the Authors analyze scaling properties of probability distributions of the peak and time to peak of topological width function. Particularly these distributions are referred to subsets of random networks, characterized by a shape parameter $\beta = \log(2\mu-1)/\log(\lambda)$, where μ and λ are the network magnitude and the network diameter, respectively.

SOIL SURFACE MORPHOLOGY EFFECTS ON OVERLAND FLOW TRIGGERING

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Soil surface morphology is one of the main parameters determining erosion and water flow at hillslope scale. Understanding effects of soil surface morphology is essential in order to traced material redistribution on surface, to couple water and sediment transport and then to improve erosion and runoff predictive models. Effects of roughness on overland flow starting were studied using a conditioned walker model. This model is able to simulate a gradual depression filling on a complex surface. With added water, a depression network develops and grows: at the beginning, few puddles are connected, catchments are small and water can be transferred on short distances only. When some filling rate is reached, water can go through the system. Depression connectivity evolution was analyzed using percolation theory. It allows a dynamic characterization of surface properties. Several surface morphologies were compared. The use of generated surfaces enables to understand relations between surface properties and overland flow triggering. The same approach has been carried out using surfaces measured on a 2.5 x 2.5 m soil box during a laboratory rainfall simulation experiment. The utility of such a model to scale up processes occurring at hillslope scale will be discussed in relation to morphologic data.

HYDROLOGICAL CONTROLS ON THE MAINTENANCE OF STEEP TROPICAL SLOPES BY MASS MOVEMENT

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The rainforest of southeast Brunei stands on a rugged, mountainous landscape which has resulted from prolonged uplift and incision. The lower valley slopes adjacent to the major rivers and minor tributaries are typically very steep (40-50°) and planar in form. A thin mantle of weathered saprolite overlies hard argillaceous shale on most of these slopes. The saprolite comprises a clay matrix with less-weathered corestones and numerous macropores. Infiltration capacities of several hundred mm h-1 and saturated hydraulic conductivities of >100 mm h-1 mean that the rate of entry of water into the soil is determined by the intensity of throughfall. Perched water tables within the saprolite develop and drain rapidly in response to high intensity rainfall and throughfall. Using a simple hillslope hydrology model with the "infinite slope" stability analysis, it was found that high magnitude rainfall events can saturate the saprolite mantle to the surface, triggering shallow mass movements if sufficient depth of saprolite is present. These shallow failures maintain the planar forms of the steep lower valley slopes.

A SEMI-DISTRIBUTED SIMULATION MODEL FOR NATURAL PIPEFLOW

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Recent field monitoring of flow in natural soil pipes has demonstrated its potential importance as a hillslope drainage process and a source of streamflow, yet few attempts have been made to model pipeflow. The most recent computer model is highly unrepresentative of the field situation. This paper describes a semi-distributed simulation model with physically based parameters that has been designed around the longest run field experiment on pipeflow. The model achieves a credible simulation, corroborating the dominance of the presumed sources of pipeflow in the conceptual model, namely lateral drainage through the pipe walls and bed and a mixture of inputs passing through the mid-slope bogs. Both rainwater infiltrating directly into pipes through the roof and capture of overland flow through blow-holes seem to be minor sources. A Darcian model is used for effluent seepage in the pipe horizon, but infiltration and transmission within the surface horizon is predominantly non-Darcian and is modelled empirically. The simulated pipe network is divided into a series of segments, to each of which is attributed a mainstream and tributary geometry representative of the real-world network. Flow is routed and accumulated by segment. The model fits 20 observed pipeflow events well.

REQUIREMENTS FOR THE SUSTAINABLE DEVELOPMENT OF MOUNTAIN TORRENTS

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The training of mountain torrents is aimed primarily at the protection of the people living along its lower courses. Disasters occur when extreme floods mobilise huge amounts of solid materials causing sedimentation and channel changes. Debris flows and/or density flows amplify these tendencies. During the last centuries these problems were attacked by an ever increasing number of check dams and slope conservation measures. This created a feeling of safety in the neighbourhood of the river but to ensure this firstly, all technical measures must be maintained and secondly, quite often the measures are outsized by natural events. The Lainbach, a test basin near Benediktbeuern in Upper Bavaria, proves that new approaches should be applied for long term disaster mitigation. By studying the worst case scenario, a combination of extreme rainfall during a wet summer with local mass movements, the potential reactions of the riverbed are estimated. In order to gain a suitable retention storage instead of building more check dams in the mountain, more space for potential sedimentation must be countered for on the alluvial fan. Short term technical solutions do not match the demands for more riverbed stability along the river course and do not add more security to the people. For the rest, the system proposed was successful during the centuries before industrialisation: so, BACK to the FUTURE!

THE MORPHOLOGICAL STRUCTURE OF MULTI-CATCHMENT REGIONS

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The morphological structure of multi-catchment regions is a topic of current research in hydrology and the assessment of the impact on such systems of meteorological events with a typical dimension in space and time suitable to cover the whole region and thus containing many scales of the hydrological response to heavy rainfall events is a challenging task with operational feedbacks. The inherent uncertainties in the prediction of the rainfall field structure suggest that a statistical characterisation of the geomorphologic features of multi-catchment regions could be useful in this context. With reference to the Liguria region of Italy (total area ≅ 5.000 km²) it may be observed that a scale factor exists for catchment areas within a region, say R_c, that – in analogy with the scale factors proposed in the Horton-Sthraler approach – is assumed of the form $R_c = \gamma R_b$. In the present paper the probability distribution of the area A_f of catchments with outlet to the sea, when measured through a reference area A_o, $P[A_f > a] = (A_f/A_o)^\beta$ is derived with $\beta = \ln R_c / \ln R_a$. The form of the distributions $P[A_{max} > a / L]$ (probability of the largest catchment in a coastal strip of linear dimension L), and $P[A_T > a / L]$ (probability of the total area of the region given L) are also easily derived. The interaction between the probability structure of catchment areas within a region with given coastal dimension L and the probability that a meteorological storm which covers the regions may contain rainfall events able to trigger hydrological resonance (crisis) of any particular class of catchments is investigated. The assessment of the expected impact of extreme events at the ground is therefore possible for a given structure of the forecasted meteorological scenario.

EXPERIMENTAL INVESTIGATION OF DRAINAGE NETWORK DEVELOPMENT

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Drainage networks are usually determined at the river system scale. Small scale drainage networks of upland eroding areas have rarely been studied. The objective of this study was i) to explore the similarities between drainage networks on eroding surfaces and those of river systems and ii) to determine the interrelationships between drainage network development and soil erosion. In flume experiments sequences of simulated rainstorms and overland flow were subjected to soils of initially different surface configurations. Before and after each rainstorm and overland flow test, digital elevation maps of the soil surface were generated using a laser scanner with 3 mm grid spacing, and drainage networks were determined. Results showed that Horton's ratios and fractal characteristics of the small scale drainage networks were similar to those of river systems. Initially different network configurations yielded different erosion values but resulted in similar network characteristics at the end of the experiments. The network changes led to network structures that resulted in continuously decreasing soil erosion values. The results support the idea of optimization in drainage network development.

ON THE HYDROLOGICAL RESPONSE OF MULTI-CATCHMENT SYSTEMS TO LARGE SCALE METEOROLOGICAL EVENTS

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With reference to the case study of the Liguria region of Italy, a multi-catchment region in the northern Mediterranean, the theoretical results obtained in La Barbera and Lanza (1998) and in Lanza and La Barbera (1998) are applied to develop a suitable operational methodology for simulation of the hydrological response to large scale meteorological events. First, identification of the scales that are involved when input is given by a meteorological model has been performed. Second, an optimal information structure for the hierarchical characterisation of a multi-catchment region has been developed, so that all targets of potential interest for civil protection purposes over the whole region are identified assumed that a given perception threshold holds. The structure is based on a topological approach and allows complete characterisation of all catchments within a region, and of the internal structure and hierarchisation of each catchment. Third a multi-catchment distributed hydrological model has been implemented, so as the hydrological response of the region may be simulated at the suitable space and time scales. Simulation of real events is presented where the assessment of the ground effects is performed in statistical terms.

La Barbera, P. and Lanza, L. (1998). On the morphological structure of multi-catchment regions. EGS XXIII Gen. Assembly, Nice (France), 20-24 April 1998.

Lanza, L. and La Barbera, P. (1998). Downscaling of rainfall predictions and uncertainty in the associated flood events at the ground. EGS XXIII Gen. Assembly, Nice (France), 20-24 April 1998.

IMPACT OF SHIP'S WAVES ON RIVER BANK DYNAMICS

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In present time the problem of impact of ship movement on environment is a very important. An impact of ship's waves on river banks, consisted of friable sandy deposits, makes dependent on the deformation of submerged bank slope. A predictive model is presented to calculate wave heights, longitudinal current velocities and sediment transport rates induced by the ship's waves. An initiation of the waves under action of moving ships is considered, wave heights and angle of the wave approach to the bank is calculated. The angle approach of the ship's waves to the bank has a great significance. The angle depends on river velocity, velocity and direction of ship movement, and changes with a change of a distance from the bank. Models of suspended sediment movement were analysed from the point of view of possibility of their application in coastal zone. On the basis of a model of deformation profile of the bank, suggested by I.O.Leont'ev, the dependence of bank slope erosion on the ship's waves was developed. If we know the composition of the rocks, making up the bank, we could calculate the maximum velocities of sediment movement along and against the current. It is possible to calculate an inverse task. Using averaged rates of ships in channels, we could create the artificial alongshore embankments.

THE TRANSITION FROM RILLED TO BRANCHED DRAINAGE IN A HILLSLOPE EVOLUTION MODEL

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It is observed in field experiments that a rilled or gullied drainage system will develop if the slope of the initially unchannelized hillslope is above a threshold value. A branched tree is formed below the threshold slope. We examine this transition quantitatively with an alluvial hillslope evolution model where the flux of sediment is proportional to the local gradient and discharge. Conservation of sediment applies and the channels dissect the hillslope with a rate proportional to the local shear stress. Drainage systems are produced with a variety of different support areas and initial slopes. A threshold product of slope and support area is observed to control the anisotropy of the resultant drainage systems. The dominant wavelength of the rilled surface in the model is related to the slope and support area and results are in agreement with field observations. The nature of the transition, whether it is abrupt or gradual, as a function slope is investigated.

HSA2 Hydrology and landforms and fluvial systems

03 Sediment and contaminant transfers at the land/ocean interface

Convener: Leeks, G.
Co-Convener: Monaco, A.

TRANSFER OF DISSOLVED INORGANIC NITROGEN TO A COASTAL LAGOON: THE CASE OF THE ARCACHON BAY (FRANCE).

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The aim of this study is to better understand the dynamic of DIN transfer from the continent to the Arcachon Bay. It consisted in monitoring during a year (December 1995 to November 1996) the dissolved inorganic nitrogen (DIN) inputs into the Arcachon Bay (France). Three different sources have been studied: direct rainfall, groundwater and rivers. The DIN fluxes measured amounted to 783 t-N for rivers (89%), 87 t-N for direct falls (10%) and 7 t-N for groundwater (1%). DIN fluxes reached the Bay mainly in the form of nitrate (818 t-N/y) which acts as an indicator of agricultural impact in this pedoclimatic environment. Study of seasonal variations has shown an imbalance of DIN input: 78% of the annual DIN inputs (684 t-N) have reached the Arcachon Bay during the high water-table period (from November 1995 to April 1996). This has been generated principally by the decrease (5 times lower) of river nitrate flux in the dry season (May to November 1996). Then, nitrate flux of groundwater remained constant throughout the year. Finally, both nitrate and ammonium fluxes of direct rain have enhanced during the dry season. They account for the third of the total DIN inputs in this period. This phenomenon may be caused by agricultural activities and an increase of tourism.

AN INVESTIGATION OF PROLONGED COASTLINE DEVELOPMENT BY COUPLED LONGSHORE/CROSSHORE MODEL

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Coupled 1D crosshore - longshore mathematical model is developed for the investigation of the coastline development in the dynamic time scale. The model includes the description of following processes (1) transformation of wave field in coastal region, (2) nearshore hydrodynamics, (3) bed and suspended load transport, (4) littoral drift, (5) beach profile development. The chain of single cross-shore models form a model for sand budget of prolonged coastline.

The forcing of the model is performed by calculation of the wave climate in far sea from meteorological observation series. The employment of model in real-time or hindcasting mode is performed using observed wind events. Analysis of prolonged (20 years) meteorological datasets has allowed to synthesize the critical and typical input data.sets for running the model in prognostic mode.

The above approach is used for about 500 km long, sandy Latvian coastline in the eastern part of Baltic Sea. The model results are compared with long-term observations of the coastline development. The agreement in determination of erosion – accretion areas and evaluation of littoral drift volume is reasonable both for coast of Baltic Proper and semi enclosed Gulf of Riga.

CAUSES AND EFFECTS OF RECENT HYDROLOGICAL CHANGES IN GREECE

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Major Greek riversÆ mean annual runoff show a significant reduction within the last two decades.The main causes are the over-exploitation of fresh water resources, mainly due to increase of agricultural activities, the droughts that affected the country during the late eighties to early nineties and the construction of hydroelectric dams and large irrigation reservoirs along the riversÆ courses. The resulting negative effects are a gradual salinisation of soils, surface and ground waters within the riversÆ catchments and especially near the coastal zone, due to sea water intrusion, a dramatic reduction in river sediment supply to the sea which cause coastal retreat, threaten important deltaic hydrotops and enhance sea water intrusion. A positive effect is the reduction of pollutant fluxes. This is not only due to the general surface runoff decrease, but also to the æfiltrationÆ of pollutants within the reservoirs. In contrast, the removal of vegetation cover through fires and extensive cultivation reduces infiltration rates and enhance, in a local scale, surface runoff, flood events and erosion processes.

LOADS OF HEAVY METALS FROM THE SCHELDT ESTUARY TO THE NORTH SEA

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A new method is presented for calculating heavy metal loads which are transported from the Scheldt estuary to the North Sea. The load of dissolved metals is obtained by multiplying dissolved metal concentrations with the river discharge, after correction for dilution with seawater. Metal loads of suspended matter are derived from concentrations in fluvial suspended matter, the supply of fluvial material, and the sedimentation of fluvial material in the mixing zone of river and sea water. Between 1987 and 1995, suspended loads of Cr, Pb, Cd, Cu and Zn decreased approximately fivefold, whereas dissolved loads of Cu and Zn increased in this period. At the landward end of the mixing zone, the loads of all metals are almost entirely carried by suspended matter. In seaward direction the water oxygen content increases, which leads to a mobilisation of Cd, Cu and Zn. Consequently, these elements reach the North Sea mainly in a dissolved form.

HSA3 Open session on hydrology and climate

Convener: O'Kane, J.P.

Representing soil water with simple models.

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Several simple soil water models with four layers or less, typical of those used in GCMs, are compared to a complex multilayered model. They are tested by applying a repeating wetting/drying cycle at different frequencies, and run to equilibrium. The ability of the simple soil models to reproduce the results of the multilayer model vary according to the frequency of the forcing cycle, the soil type, the number of layers and the depth of the top layer of the model. The best overall performance was from the four layer model. The two layer model with a thin top layer (0.1m) modelled sandy soils well while the model with a thick top layer (0.5m) modelled clay soils well. The model with just one layer overestimated evaporation during long dry periods for all soil types.

INFLUENCE OF CLIMATIC MODIFICATIONS ON GROUNDWATER AND ENVIRONMENT.

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The modifications, wich are predicted by the climatologists of the whole world: global air temperature changes and quantitative performances of atmospheric precipitation,evaporation and evaporability, will be reflected in conditions of a hydroorb as a whole,including groundwater, enclosing geological medium and social conditions. The given circumstance binds to study and predict these modifications carefully. Deglaciation of continental ice, first of all in Antarctica, will cause not only flooding of territories, but also will cause backwater effect of huge seaside territories, much more exceeding the flood areas. So, St.-Petersburg and Arkhangelsk cities will be flooded partly, but the other areas of the cities and large part of administrative areas will feel backwater effect, that will limit some kinds of economic activity.

EFFECTS OF POTENTIAL CLIMATE CHANGE ON HYDROLOGIC VARIABILITY IN THE ARNO BASIN

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Local precipitation and temperature scenarios downscaled from Global Circulation Models (GCMs) predictions through a stochastic approach have been used to assess how man-induced fluctuations of climate, temperature and precipitation distribution could affect the water balance and the discharge regime of the Arno river (Central Italy). Local and basin scenarios reflected the changes predicted by the United Kingdom MetOffice high resolution GCMs. Both the equilibrium and the transient scenarios from GCMs have been used to investigate the hydrologic sensitivity of the basin to a range of potential future climates. Changes at the annual and monthly scales have been investigated, both in terms of temporal distribution and statistical properties. The study also addressed the effects on low flows and floods, so highlighting potential impacts which might affect water balance and flood risk. Furthermore, basin scale influence has been addressed, by analysing the sensitivity of changes to basin size and characteristics. The results show first that trends exhibited by rainfall scenarios are sometimes enhanced, sometimes smoothed by runoff generation mechanism, due to the effective role of the different processes involved in the transformation. In addition, smaller scales show larger increases of the distribution tail of monthly runoff, whereas low flows - sometimes higher under the modified scenario that under the control climate - exhibit a major sensitivity at larger than at smaller scales.

MONITORING DROUGHT IN HUNGARY USING THE STANDARDIZED PRECIPITATION INDEX

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The Standardized Precipitation Index (SPI) was developed in 1993 by researchers at Colorado State University in response to their need for a simple, flexible drought index to monitor moisture conditions. Since then, the SPI has been widely applied at national, regional, and local levels throughout the United States. One of the big advantages of the SPI is its multiple time scale capability that allows monitoring of different water resources. In 1997, the Hungarian Meteorological Service began a joint agrometeorological project with the United States-based National Drought Mitigation Center (NDMC), and one of the project's products has been the application of the SPI to fifteen long-term sites around Hungary. Recent droughts have had major impacts in Hungary, and the objective of this paper is to evaluate the success of the SPI in detecting and monitoring drought conditions around the country. Time series of the SPI at different time scales and locations are examined and compared with the Palmer Drought Severity Index (PDSI). Characteristics of Hungarian droughts are identified, and recent droughts are put into a historical perspective. These analyses demonstrate that the SPI can become a valuable tool for drought early warning and monitoring in Hungary.

EXTREME RAINFALLS IN THE CHANGING CLIMATE: REGIONAL ANALYSIS AND HYDROLOGICAL IMPLICATIONS

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A comprehensive analysis of the extreme rainfalls in Tuscany, Italy, is carried on with several aims.
Uncertainties related to the estimate of the design storms at several representative sites are analysed through the application of the Generalised Extreme Value (GEV) distribution.
Cycles up to the long range dependence are drawn from hystorical series.
Possible trends in the extremal data are estimated through the application of an ARIMA model.
Hydrological consequences of such observed uncertainties and trends are inferred in terms of flood risk and hydraulic works in small-medium size basins.
A preliminary study concerning the effects of different scenarios of global warming on extreme rainfalls at the regional scale was performed. Hydrological implications are thus derived as above.

VALIDATION OF GCM PRECIPITATION OUTPUT USING THE METHOD OF FRAGMENTS

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The method of fragments can be used to generate monthly precipitation totals, from aggregated annual values, preserving statistical properties as mean values, standard deviation, skewness and lag one correlation coefficients, at both aggregation levels. This method was used to validate monthly rainfall output from the 2nd Hadley Centre Coupled Ocean-Atmosphere General Circulation Model (OAGCM), comparing statistical properties of observational time series, of the monthly time series computed from the OAGMC, and of time series obtained disaggregating annual OAGCM precipitation values using fragments computed from observational data. In order to perform these comparisions a point in OAGCM grid was chosen together with an observation station closely located to the grid point. Statistical properties were compared for annual and monthly time series. Results for monthly disaggregation show that the method of fragments gives in general results with the same statistical quality as those of the OAGCM.

From GCMs to river flow: A review of downscaling and hydrological modelling approaches

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One of the most significant potential consequences of changes in climate may be alterations in regional hydrological cycles and subsequent changes in river quantity and quality regimes. There exist spatial and temporal scale mismatches between GCMs and catchment models, the so-called 'downscaling' techniques have been subsequently emerged to bridge the gap. This paper reviews, in a hydrological context, the various methods for simulating hydrological responses to global climate change. These include (1) the direct use of GCM-derived hydrological output, (2) coupling GCMs with macroscale hydrologic models for large river basins, (3) coupling GCMs with catchment models through downscaling techniques, and (4) using hypothetical scenarios as input to hydrologic models. Methodologies are reviewed, deficiencies are discussed, and additional research needs are identified.

DOWNSCALING GCM LARGE-SCALE INFORMATION TO REGIONAL CLIMATE SCENARIO: A WEATHER GENERATOR BASED ON DAILY CIRCULATION PATTERNS

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Stochastically downscaling techniques are widely used to obtain regional climate scenarios from GCM large-scale information. In this study, a weather generator has been developed to generate future climate scenarios of daily precipitation in Portugal, based on daily circulation patterns. The whole procedure is described as follows: first, daily circulation patterns are classified from observed daily sea level pressure fields over North Atlantic and West Europe by K-means clustering algorithm coupled with principal component analysis; second, a stochastic model of occurrence of rain based on daily circulation patterns is calibrated; third, a probability distribution of rainfall amounts on rain days is fitted conditioned on daily circulation patterns; fourth, GCM output on daily circulation patterns is validated; finally, stochastic models conditioned on daily circulation patterns classified from daily GCM output are used, to obtain future daily precipitation scenarios. A first-order Markov chain is applied to simulate the occurrence of rain and a two parameter Gamma distribution is employed to generate daily rainfall amounts. This weather generator can well simulate the occurrence of rain, as well as the properties of rainfall amounts, and even useful information on extreme rainfall.

ANTHROPOGENIC POLLUTION OF RIVER BASINS IN THE FORMER SOVIET UNION

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Sulphate and chloride ions have a high migration capacity and can be registered practically in all natural waters. Correct determination of these components has an important significance by solving problems of salt-accomplishing, selection of perspective water basins as sources of fresh water, etc. For estimation of contents of natural and anthropogenic sulphate and chloride components in the outflow sections of 220 rivers of the Former Soviet Union (*FSU*) the data of systematic observations in all regions have been used. These data have been analyzed and generalized. For instance, according to our calculations, sulphate anthropogenic factor consists of about 50% of modern pollutions and chloride anthropogenic factor – about 30%. The total outflow of sulphates and chlorides in the *FSU* consists of $104.7 \cdot 10^9$ kg and $87.2 \cdot 10^9$ kg, respectively. The calculations show that the largest Russian rivers Volga and Lena are characterized by the greatest sulphate and chloride outflows reaching (a) Volga: $19.93 \cdot 10^9$ kg (sulphate) and $12.09 \cdot 10^9$ kg (chloride); (b) Lena: $16.01 \cdot 10^9$ kg (sulphate) and $19.55 \cdot 10^9$ kg (chloride). Atmospheric sulphate component of river flow in the *FSU* is estimated as 24% on the base of calculations of annual sulphate atmospheric fallout (with precipitation) over large river's basins and hydrographic regions where this value varies from 5% to 33%.

A NEW PARAMETERIZATION OF SOIL HYDROLOGY IN THE LMD GCM.

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It is widely recognized that the land hydrology plays a fundamental role in the climate. The atmospheric water cycle is crucial for the redistribution of solar energy through evaporation, precipitation and water vapor transport. In GCMs, the parameterization of land surface processes is important as it determines the lower boundary conditions of the model and the partitioning between sensible and latent heat fluxes. The LMD GCM uses the complex land surface scheme SECHIBA. In a recent study, we have shown that the too simple representation of hydrology in SECHIBA leads to an overestimate of the global evapotranspiration due to an insufficient control by the soil hydrology on the evapotranspiration. We describe here a new version of SECHIBA which includes eleven soil moisture layers and takes into account the resolution of the Richards equation for water diffusion in porous media. It is derived from the model of CWRR of Dublin. In the GCM, a tile approach is used to represent the sub-grid variability of soil characteristics. Such a hydrological model allows, through a better representation of the vertical distribution of soil water, an improved modeling of evapotranspiration. We will show the impact of the improved representation of soil hydrology on the partitioning of surface fluxes between latent and sensible heat. The climate inter annual variability will be also studied as the memory of soil moisture is extended beyond seasonal scales.

THE KARSTIC AQUIFER OF SOUTH DOBROGEA – RESOURCES AND POLLUTION

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Based on the chemical analyses made on over 20 water samples, the paper presents, in its first part, the main characteristics of the groundwater of the two main aquifers in the southern part of Dobrogea, one of the most important groundwater resource: pH, temperature, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, SO_4^{2-}, NO_3^{-}, etc. The second part of the paper exposes a method of calculation in order to determine the radiometric ages of the groundwater using analyses based on C^{14}. The image of the groundwater flow spectrum in the aquifer of a Jurassic type was drawn considering these data and relating them with the chemical analyses results. The conclusions and suggestions for the future research directions which have to be followed to improve the knowledge on the two aquifers can be formulated and we expect that the necessity to identify the natural discharge areas on the Bulgarian territory is a priority.

SENSITIVITY OF THE GLOBAL WATER CYCLE TO SOIL WATER-HOLDING CAPACITY

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The sensitivity of the hydrological cycle to soil water-holding capacity (WHC) is investigated with the LMD-GCM coupled to the land-surface scheme SECHIBA. This scheme includes a resistance formulation for evaporative fluxes, a one-meter soil, a drainage term and an overflow runoff when soil moisture reaches the WHC, which is regarded as an available capacity. In the reference simulation S1, the WHC uniformly equals 150 $kg.m^{-2}$. Two simulations S2 and S3 are conducted with spatially variable WHC from observational data sets: S2 makes use of available WHCs, with a global average slightly smaller than in S1; S3 makes use of a total WHC data set, which is not realistic but is meant to assess the impact of a large increase of the WHC (its global average is more than twice as large as in S1).
The simulations are run for 9 years after spin-up. On the average over the continents, the soil moisture increases from S2 to S1 to S3, but the evaporation and precipitation rates increase from S1 to S2 to S3, with total runoff and moisture convergence decreasing from S1 to S2 to S3. These interesting results are explored through an analysis of the changes in the atmospheric circulation.

FEATURES OF THE GEOCHEMICAL ANOMALY ASSUMED FROM THE CONTENTS OF SOME CHEMICAL ELEMENTS IN MEDITERRANEAN SEA WATERS NEAR THE NILE RIVER DELTA

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During 1988 and 1990, two Russian-Egyptian expeditions was conducted within the avandelta of the Nile River on the boards of vessels of Russian Academy of Sciences. Their aims were problems of the elucidation of the functional relationship between the spatial variability of *Al, Fe, Mn, Zn, Ni, Co, Pb, Cu, Cd* contents in the suspended matter from their terrigenous sources and different hydrophysical, hydrochemical and hydrobiological processes.

As it was established, the mean contents of chemical elements in avandelta waters differ from the corresponding contents in the suspended matter of the greatest rivers of the World. So, the specific contents of the elements -hydrolizates as *Al, Fe* and *Mn*, were 1.2-1.3 times less than in the World rivers on the average. For *Zn, Ni, Co, Pb, Cu* and *Cd*, these values were, in contrast, 2-20 times more, and the differences between maximal and minimal specific contents ranged up to two orders of magnitude.

EFFECT OF COUPLING BETWEEN A VEGETATION CANOPY AND THE ATMOSPHERE ON ENERGY AND WATER TRANSFER - RESULTS WITH THE MODEL HIRVAC

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The vegetation is an important interface between the soil and the atmosphere. Height, density and type of vegetation influence water and carbon dioxide cycle as well as the energy balance over areas with different scales. Under special conditions coupling and feedback mechanisms between the vegetation and the atmosphere occur. The coupling degree depends on local conditions of radiation as well as on vertical and horizontal extension and texture of the canopy. To study results of coupling mechanisms on energy and water transfer between soil, vegetation (especially a forest canopy) and atmosphere and consequently the effect on local climate the model HIRVAC (HIgh Resolution Vegtation Atmosphere Coupler) has been developed. HIRVAC is a high resoluted one-dimensional atmospheric boundary layer model (120 model layers, about 60 inside the canopy with a characteristic forest height of 30 meters) coupled with a single-leaf gas exchange model (see presentation from Goldberg and Falge at the Vienna EGS General Assembly). The model HIRVAC is able to simulate the response of different vegetation types to a continously changing atmospheric environment. First results of numerical experiments illustrate the strong dependence of interaction between coupling mechanisms of energy and water transfer from soil and vegetation to the atmosphere on atmospheric boundary conditions (radiation input, stratification, geostrophic wind and season) as well as on vegetation type (forest, meadow) and structure. The improvement of the soil model and the optional use of an additional counter-gradient term in the flux relationship lead to a better resemblance of numerical and experimental results. The comparison between model and experiment also shows the need for a better radiation modeling within the canopy.

KARST IN AN ACTIVE SALT ROCK DOME.

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Karst in salt-rock displays some distinctive features compared to those more typically developed in limestones. High solubility of salt exerts control on morphology and on time evolution of land forms. On one side, groundwater reaches NaCl saturation easily, which tends to prevent caverns to progress downwards. More often underground features take on the form of wide, planar developments with minor vertical height. Underground collapses close to the surface are frequent. Land forms evolve rapidly even under semiarid conditions (P<400 mm) which causes landscape to change on a yearly basis with severe implications for urban development. The Cardona Salt Dome (Barcelona, Spain) is world wide known due to mining of potash down to -1100 m below ground. The dome outcrops and still rises at an average rate of 3-5 cm/year. Hydrological studies at the outcrop area (2 km2) establish that most of groundwater flows relatively close to surface. The interface at the overburden with the salt-rock plays a preferential flow path role, which enhances solubility of the salt during rain periods. Karst underground morphology has been conjectured and proved by direct and indirect methods. Hydrogeochemical modelling shows that brackish water originates at fresh water areas, and precipitation of gypsum and calcite is needed to maintain equilibrium, which has been observed in cores. The system discharges to a river basin, where outflows have been estimated to be 12l/s after careful mass balances.

DIMENSIONALITY OF SCANDINAVIAN RIVER FLOW REGIMES

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A river flow regime describes an average seasonal behaviour of river flow, usually basing on long term monthly mean values. It reflects climatic and physiographic conditions in a basin. Seasonal patterns of flow can be regular, repeating in principle the same pattern from year to year, or irregular, i.e. alternating between a couple of different regime types during individual years. Stability of river flow regimes is a characteristic of much importance for hydrological regionalisation and for sustainable water management. It is also one of the environmental constraints for many aquatic and river basin related biological species. By tradition a river flow regime has been considered as a static characteristic, which is an oversimplification with regard to constantly changing environmental conditions. To follow the development of the flow regimes in time a deeper insight into the complexity of variations of seasonal flow patterns is needed. This paper investigates the dimensional structure of seasonal patterns of Scandinavian river flow regimes from two perspectives *viz.* a fractal dimension of a dynamic system and intrinsic dimension of a point set of data.

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ON SPATIAL AND TEMPORAL VARIABILITY OF SELECTED SOIL MOISTURE CHARACTERISTICS

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Long (1881-1990) series of soil moisture conditions characterised by four estimated parameters are investigated. These are (i) the standard Palmer Drought Severity Index (PDSI), (ii) its monthly increment (Z-index), (iii) and (iv) two differently estimated numerical series of soil moisture content (SMC) of the upper 1.0 m layer, all computed from monthly precipitation and air temperature data. Besides the derivation and comparison of some basic statistical parameters, two further aspects are tackled: First, spatial distribution patterns are determined by using factor analysis (FA). FA determines geographical regions with inter-annual anomalies that appear similarly within a given region, but differently in the other ones. The results of FA are tested with respect to the number of stations and to the time interval, they are computed from. Second, time variability is characterised for the representative stations of each region, also derived from the FA, namely the (S)ARIMA-structure to characterise both intra- and inter-annual variability, and also the long-term trends. The latter problem is considered in connection with the global climate variations, too. Linear regression of the soil moisture parameters to the hemispherical mean temperatures and continent-ocean temperature contrast are computed. Significant negative regression coefficients in the warm period of the year project an increase in the frequency of droughts, if global warming continues.

RESOURCE DEVELOPMENT AND MANAGEMENT IN THE KARST AQUIFER SYSTEM OF MEDGIDIA AREA, ROMANIA

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The paper presents the main results of a long period with the complex studies to establish the resource development of one of the very important karst aquifer systems of Romania. Only the correct interpretation of the field data have lead, finally, at the design and achievement of a well field with the yield of 1,000 l/s drinking water. The well field has start its operation since 1989 and it was permanently monitored, its management showing some technical and economical problems, very important in connection with the behavior of the karst aquifer systems. All these data - field measured (quantitative and qualitative parameters of the aquifer system) and surely computed data (based on the in situ measured parameters) - are presented in the paper. The results were used to improve the management of the system in its hole complexity. The sources of groundwater pollution are also analyzed, so that the measures for groundwater protection can be taken.

SIMULATION OF CLIMATE CHANGE IMPACTS ON RIVER RUNOFF: COUPLING HISTORICAL AND MODELLING APPROACHES

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An application of a regional distributed hydrological model ECOMAG to study of climate change impact on river runoff in the NOPEX experimental area (80x100 km), situated in the southern Sweden, is considered. An analysis of the observed meteorological data for 15 years (1981-1995) has shown that the cold and moist years dominated in the first half of this period, while relatively warm and dry years have been observed mostly during the last years. The observed series were divided in two subsets: 1981-88 ("cold" years) and 1989-1995 ("warm" years). The differences in temperature between two subsets (an increase in average annual temperature by 1.4oC and to 5oC during winter months) are very similar to those, simulated by GCMs for warming in the next century due to the expected doubling of CO2 concentration. A comparison the changes in simulated runoff to the observed ones during the non-stationary climatic period is very useful validation of hydrological models used to study climate change impact on water resources and that might reduce many uncertainties connected with adequacy of the hydrological models.

CHANGES IN WATER BALANCE COMPONENTS UNDER GLOBAL WARMING AND CONSEQUENCES FOR CIS AGRICULTURAL AREAS

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Under different Global Warming schemes it is possible the increase of annual precipitation will be from 30 to 40 % in Eurasian arid regions. Therefor it is necessary both to have a long-term forecast of changing water balance components of agricultural areas and to assess a great number of consequences of their manifestation such as changes of crop yields, water consumption rates and other things. Authors present the results of assessing changes expected in water balance components, mainly soil moisture content and evapotranspiration of agricultural areas in arid and semiarid zones of CIS.

DOWNSCALING PRECIPITATION AND POTENTIAL EVAPOTRANSPIRATION FROM GCM OUTPUT TO DRIVE A HYDROLOGICAL SIMULATION MODEL AT CATCHMENT SCALE

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General Circulation Models (GCMs) are unable to produce precipitation and potential evapotranspiration (PET) scenarios at the spatial and temporal resolutions required to assess the hydrological impact of climate change at the catchment scale. To overcome the disparity of scales, statistical relationships were established between three indices of atmospheric circulation (vorticity, flow strength and direction of flow) and daily catchment precipitation and PET to downscale from the HadCM2 GCM to the Upper Wye experimental catchment in mid-Wales. The effectiveness of the approach was assessed by comparing the downscaled variables for present (Grid based 1975-1990), 'simulated' present (HadCM2SUL 1980-1999) and future (HadCM2SUL 2080-2099) conditions with recorded precipitation and PET at the Upper Wye catchment. Errors were calculated as the difference between the recorded and the downscaled present precipitation and PET. It is suggested that the low sensitivity of the atmospheric circulation indices to greenhouse gas forcing in HadCM2 subdues the changes in the downscaled variables between 1980-1999 and 2080-2099. The parameters of a hydrological simulation model (HYSIM) are estimated and the model is evaluated against recorded flow data. HYSIM was 'forced' using the downscaled precipitation and PET scenarios to model the changes in hydrology. The source and extent of the uncertainty involved was evaluated by comparing the hydrological change between 1980-1999 and 2080-2099 with errors arising from the downscaling technique.

REFERENCE EVAPOTRANSPIRATION ESTIMATING FOR HYDROLOGICAL PURPOSES

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Reference evapotranspiration (ETr, loss of water from grass in best nutrient and water conditions) is a key concept in hydrological models at regional scale. Many ETr models have been developed in the last few decades, most of these are empirical and do not work in any site. The best analytical model is the Penman-Monteith one, but in this case a parameter is difficult to evaluate both on a hourly and daily scale: the canopy resistance (r_c). In fact, actually, it depends on weather, and it is influenced by agronomic practices (irrigation, grass cutting) and time scale but, for reference grass, usually it is assumed constant or it is modelled only in function of leaf surface. In this work we propose a model of r_c dependent on standard climatic parameter (available energy, air vapour pressure and temperature, aerodynamic resistance). It was formulated at hourly scale, but it can be generalized at daily scale also. The ETr estimated using this model of r_c is compared with direct measurements from a weighing lysimeter, in a region submitted to semi-arid Mediterranean climate (Southern Italy), for a period of two years. The results showed a very good performance of the model both on a hourly and daily scale. In particular, on a daily scale, the model presents only a very little underestimation (about 2%), so that it is accurate enough to be used for hydrological purposes. An independent test on this r_c model showed that it is valid also under tropical humid climate.

THE EFFECTS OF POSSIBLE FUTURE CLIMATE AND LAND USE CHANGE ON STREAMFLOW FROM CONTRASTING CATCHMENT AREAS IN THE UK AND THE AVAILABLE MANAGEMENT OPTIONS TO AMELIORATE THESE EFFECTS

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The effects of possible future climate change on streamflow from a number of contrasting catchment areas were estimated using a process based approach. It was found that, for high rainfall upland areas, streamflow would increase, particularly during the winter months. Whilst this is generally beneficial for water supply and river regulation reservoirs, there is a danger of an increase in downstream flooding. In contrast, streamflow from low rainfall lowland areas are predicted to decrease, with the highest percentage decreases occurring during the summer months. This has obvious implications for agriculture, particularly in those areas where crops are irrigated during dry periods.

Any future climate change will be accompanied by land use change. This will also result in changes in streamflow. The implications of these various changes on water supply are discussed, and the management options available to ameliorate the effects are examined.

A METHOD FOR DROUGHT MONITORING

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Droughts are natural phenomena that affect eventually the Portuguese territory, generating important losses in several social and economical activities. Drought prevention includes the development of monitoring methods adapted to the characteristics of the regions. A regional drought distribution model enables one to determine the area-severity-frequency of the drought event using long-term series of annual precipitation data. Based on this model a procedure has been developed to monitor regional droughts on a real-time basis. This procedure consists on the prediction of the annual precipitation, and thus the prediction of the drought event, based on the sequent analysis of cumulative monthly precipitation data at the end of each month. The prediction of droughts enables to undertake the measures required to mitigate the expected drought effects.

NORMAL EVAPOTRANSPIRATION IN DIFFERENT LAND TYPES: AGRICULTURAL FIELDS AND RIVER BASINS

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The comparison have been carried out led us to propose that the normal evapotranspiration from the agricultural fields during frost-free period is approximately equal to the normal annual evapotranspiration from the catchment basins. The normal evapotranspiration from the agricultural fields of the forest-steppe and steppe zones of the Former Soviet Union during the frost-free period was calculated using standard observational data of agrometeorological stations. The maps of the normal annual evapotranspiration from the catchment basins in the same region which foundation is water balance method constructed by (I) P.S.Kuzin using measured precipitation and (ii) N.N.Dreier using precipitation including correction to measured precipitation were used. The results of the comparison are as follows. In the first case the evapotranspiration from agricultural fields are somewhat more than the water balance data for evapotranspiration from the catchment basins by P.S.Kuzin. The reason has to do with underestimating of the winter precipitation being used. The water balance data for evapotranspiration from the catchment basins by N.N.Dreier far exceed the evapotranspiration from agricultural fields. The reason is that the correction to measured precipitation is essentially overestimated.

APPLICATION OF THE UP MODELLING SYSTEM TO THE ARKANSAS RED RIVER BASIN

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The UP modelling system has been designed to simulate large scale hydrology and to interact with climate and weather forecasting models. The modelling approach differs from that taken in all the other currently available models designed for this purpose in two respects. First, whereas most other approaches rely heavily on calibration against existing hydrological data the UP approach keeps this to a minimum and attempts to retain a physical basis so that changes in the physical properties and forcing variables are reflected appropriately in the model results. Second, it explicitly represents the movement of groundwater in regional aquifers; this is a part of the hydrological cycle often neglected in other large scale hydrological models but which has the potential to redistribute water, albeit slowly, over very large areas.

The UP system has been applied to the Arkansas-Red river basin which covers approximately 570000km^2 of central USA, east of the Rocky Mountains. The basin is hydrologically diverse and encompasses, *inter alia*, large regional aquifers, karst regions and regions in the high rocky mountains where most of precipitation falls as snow. The application serves to highlight the strengths of a physically based modelling approach to a complex large river basin.

MODELING RUNOFF IN AMAZONIA USING SEA SURFACE TEMPERATURE

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Variations in the pattern of the Atlantic and Pacific sea surface temperature (SST) are known to influence the precipitation-runoff processes in Amazonia. Variations in the SST patterns are related to climate variability in Amazonia. This study analyses different data driven techniques to model runoff in the Amazon Basin using Pacific and Atlantic SST one or two seasons in advance as predictor. Models were developed using Canonical Correlation Analysis (CCA) and Artificial Neural Network (ANN). Results showed that the Pacific SST has a stronger influence on the precipitation-runoff processes of the northern Amazonia and Atlantic SST on the southern Amazonia. A comparison between the two techniques showed that ANN has better kill when compared to the CCA. This result was somewhat expected considering the known non-linearity of the processes that drives from the SST to the precipitation and from this to runoff.

PRECIPITATION FORECASTING FOR DIFFERENT TIME SCALES.

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Precipitation forecasting is necessary for different watermanagement purposes. Short term forecasting is necessary for flood protection. It is mostly based on measurements and meteorological models. Seasonal forecasting can be used for reservoir operation and to a certain extent for flood prevention. This cannot be done with meteorological models only. Thus other variables like North Atlantic Oscillation Index and Sea Surface Temperature anomalies are used. There is a dependence between these variables and monthly precipitation amounts and extreme daily precipitation. Due the timeshift of a few months this relationship can be used for seasonal forecasting. This is shown on exemples in different catchments (Ruhr, Aller). For design purposes longterm "forecasts" (10-100 years) are required. Here assumptions on stationarity of precipitation or a changing climate have to be taken in consideration. In case of climate change GCM forecasts are required and have to be downscaled. This problem is also discussed and a case study on the Aller catchment is presented.

DIFFERENCES IN STABLE ISOTOPIC COMPOSITION OF GROUNDWATER BETWEEN THE SLOPES -A CASE STUDY ON MT. YATSUGATAKE AND MT. FUJI, JAPAN-

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Mt. Yatsugatake and Mt. Fuji , 2899 m and 3776 m high respectively, are dormant volcanoes in central Japan. For Mt. Yatsugatake, groundwaters on the west slope, which is on the leeward side of the mountain, are more isotopically depleted in δD by about 10‰ than those of comparable elevations on the east slope. A similar situation exists for Mt. Fuji, for which groundwaters on the north slope (leeward side) are more isotopically depleted in δD by >10‰ than those of the other slopes (windward side). Differences in δD of groundwaters between the slopes on each of Mt. Yatsugatake and Mt. Fuji can be attributed to different processes for the respective volcanoes. For Mt. Yatsugatake, less evaporation on the leeward west slope results in isotopically depleted groundwaters on the leeward west slope. In contrast, isotopically depleted precipitation on the leeward north slope of Mt. Fuji, which is caused by the rain-shadowing effect of the mountain, is most responsible for isotopically depleted groundwaters on the same slope.

HSA4 Open session on hydrology and weather

Convener: Burlando, P.

CHARACTERISTIC OF HIGH WATER AND DROUGHTY PERIODS IN THE CARPATHIAN REGION INDUCED BY VARIABILITIES IN THE LARGE SCALE CIRCULATION

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In this paper the alternance of the high water and draughty periods is analysed in the Carpathian Region, in connection with the precipitation characteristics induced by the large scale circulation. As a general characteristic for all the rivers in Carpathian Region, 1931-1941, 1964/1965-1981 are rainy periods and 1941-1951, 1981-1995 are draughty periods. The starting point of each period of specific phenomenon could vary with one or two years, depending of the inertia of the hydrographic basin at the precipitation amounts. The corresponding downward/upward change points which mark the series (or sub-series) of data show that the high water are installed with 1964/1965 for the intra-Carpathian stations and in the region of the curve of the Romanian Carpathian Mountains. In the eastern part, 1968 was revealed. 1981 appeared as a downward change point for almost the entire area for the annual mean series of discharges. It can be noticed that from the point of view of the evolution in time, the frequency of the draughty years has increased almost continuously at the South of the Carpathian Mountains, fact what could show an aridisation trend for the area. The winter season discharges show a decreasing tendency for almost the entire area, an exception beeing the Moldavian Region. In summer season an increasing tendency is revealed. The CCA analysis illustrate that these systematic changes induced in flow by precipitation are connected mainly with changes of south-westerly circulation which brings moist Mediterannean air in the Carpathians Region and with the frequency (or intensity) of the north-westerly circulation.

Disaggregation of highly seasonal monthly rainfall by simulating annealling

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The need for high resolution rainfall data at temporal scales varying from daily to hourly or even minutes is a very important problem in hydrology. For many locations of the world, rainfall data quality is very poor and reliable measurements are only available at a coarse time resolution such as monthly. The purpose of this work is to apply a mixed method for the disaggregation of monthly precipitation to daily. The method consists of three steps: 1. Assessment of the number of wet days as a random variable conditional to the monthly amount based on the Polya distribution 2. Division of the monthly sum among the wet days using Aitchinson's relative amount distribution. 3. Restructuring of the series according time series properties (autocorrelation function, scaling, wet-dry duration distributions using a Monte Carlo Markov Chain based algorithm. The method was applied to a data set from a rainfall network of the central plains of Venezuela. The application requires the regionalization of the daily rainfall charachteristics. A detailed analysis was carried out to study the seasonal ad spatial variability of many properties of the daily rainfall as scaling properties, duration of wet and dry periods and autocorrelation function in order to incorporate the selected properties and their annual cycle into the objective function. Comparisons between the observed and simulated data suggest the adequacy of the technique in providing rainfall sequences with consistent statistical properties at a daily time scale given the monthly totals.

HYDROLOGIC ASSESSMENT OF REAL-TIME BIAS ADJUSTMENT PROCEDURES IN RADAR-RAINFALL ESTIMATION

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Radar rainfall measurements over mountainous terrain are associated with mean-field and range-dependent biases. A set of procedures devoted to the real-time correction of these errors is proposed here. Range-related biases are corrected by converting radar reflectivity measurements at a given altitude into their equivalent surface values, using real-time identification of the mean vertical reflectivity profile. Mean-field bias is adjusted using a multiplicative factor which is statistically determined based on real-time radar-raingage comparisons. The impact of the above errors and the improvements obtained using the correction procedures is assessed in the context of runoff forecasting of several flood-inducing storms in a mountainous region in northern Italy. The investigation uses data from the Monte Grande C-band radar (Italy) and from a dense raingage network. The study area covers two catchments, Posina (116 km2) and Alpone (77 km2), which are located approximately 60 km and 40 km from the radar site. The hydrologic models employed are the TOPMODEL and the Probability Distributed Model. Radar rainfall estimates (before and after correction), as well as raingage rainfall accumulations, are input into the rainfall-runoff models for flood simulation. Comparisons between simulated and observed hydrographs from several storm events are used to evaluate the proposed error correction procedures, and to demonstrate the value of distributed rainfall information in hydrologic forecasting.

PERFORMANCE OF THE SWISS MODEL: COMPARISONS WITH OBSERVATIONS AT THE HYDROLOGICAL STATION OF RIETHOLZBACH

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The correct treatment of surface fluxes is essential in numerical weather prediction (NWP), making it necessary to model soil-atmosphere processes accurately. Particularly the soil moisture plays an important role in the prediction of surface fluxes as well as screen level parameters (temperature and relative humidity). Given only sparse soil moisture observations, it is a challenge to verify the soil moisture in models.

In this paper the performance of the land-surface scheme of the Swiss Model, the operational meso-β-scale NWP model of SMI, has been evaluated at one grid point with in situ measurements provided by the hydrological station of Rietholzbach, Switzerland. Parameters such as evapotranspiration, soil moisture as well as temperature and relative humidity have been compared with the output given by the SM for the summer periods of 95 and 96.

RAINFALL GENERATOR FOR THE RHINE BASIN: MULTI-SITE GENERATION OF WEATHER VARIABLES BY NEAREST-NEIGHBOUR RESAMPLING

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A multi-site rainfall generator is being developed using a nonparametric nearest-neigbour resampling technique for time series of daily rainfall in the German part of the Rhine basin. The request for this rainfall generator came from the Institute for Inland Water Management and Waste Water Treatment RIZA. It arose from the need to get better insight into the likelihood of extreme river discharges in the Netherlands. In the nearest-neighbour method, precipitation for a new day is sampled with replacement from analogues in the historic record. Different sets of weather variables and circulation indices are compared for the selection of these analogues. The emphasis in this comparison is on the reproduction of the autocorrelation structure and the distribution of multi-day maximum precipitation amounts. Snow accumulation and melt are also discussed. Although resampling is done for present-day conditions, it can easily be adapted for climate change applications.

COMBINED USE OF REMOTELY SENSED DATA AND GROUND OBSERVATION FOR THE ESTIMATON OF SOIL MOISTURE CONDITIONS

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One of the most important parameters that influences the rainfall-runoff process is the watershed saturation condition. When real time flash flood prediction is of concern, simple procedures for the estimation of soil moisture conditions, exploitable in an operational framework, are needed. This work presents an attempt to estimate the soil moisture conditions, for the initialisation of rainfall-runoff models for flood prediction, based on the combination of weather data recorded by ground stations (raingauge networks) and near IR images provided by geosyncronous satellites (Meteosat). IR cloud temperature surveyed by the Meteosat sensor is used in order to define rainy clouds. Precipitation data provided by real time ground observation are processed in order to obtain 24-48 hrs antecedent cumulated point rainfall depths. These values are then interpolated over a spatial domain where rainy clouds were present during the same interval. Spatially interpolated rainfall depth is then used for antecedent soil moisture evaluation within a rainfall-runoff model. The method can be applied, for its robustness and fastness, within a real time procedure for flash flood prediction.

RELATION BETWEEN THE RAINWATER CHEMICAL AND ISOTOPIC CONTENT AND THE METEOROLOGICAL PARAMETERS IN THE WESTERN MEDITERRANEAN REGION

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Stable environmental isotopes, abundance of major ions and chemical composition of atmospheric deposition have been observed on the western part of the Mediterranean basin. Using a network including 25 stations located in the seaside countries (18 managed by International Atomic Energy Agency, 7 by University of Avignon), spatial and seasonal variations of the Mediterranean precipitations can be related to the air masses' back trajectories and the meteorological parameters. The use of the rainwater isotopic content database provided by the IAEA European network underline the seasonal variations of deuterium excess (d). The average of d in the study area allows to discriminate the winter (d = 13.27‰) and the summer (d = 3.56‰) precipitations as well as the location and the climatic conditions of all the meteorological stations: Porto (41.08N - 8.36W) with oceanic influence (d = 9.38‰), Barcelone (41.38N - 2.12E) with Mediterranean influence (d = 11.07 ‰). These preliminary results in association with water chemistry and aerosols contents investigation show the importance of the local meteorological conditions and especially the mixing between Atlantic and Mediterranean influences, in the determination of rainfall isotopic and chemical composition.

VERIFICATION OF MODEL-PREDICTED MESOSCALE RAINFALL PATTERNS IN AN ALPINE AREA

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Alpine rainfall patterns typically exhibit a strong precipitation gradient across the main divide due to upslope enhancement and lee drying. Superimposed are smaller scale structures caused by local topographic effects like channeling and blocking and by the release of convective energy triggered by these effects. Quantitative precipi-tation forecasts in the Alpine area require prediction of the varying strength and po-sition of the main cross-divide gradient and the changing location of individual ma-xima and minima within the upslope precipitation belt. An operational limited area model (ALADIN) and a semi-analytical orographic precipitation model (OPM) are used to study the skill of short-range forecasts of these features with regard to hy-drological applications. Model results are compared with observations from a dense operational raingauge network. While both models generally underestimate the me-so-a along-range variation in rainfall intensity, the upslope/leeside contrast and the position of maximum rainfall is satisfactorily reproduced, particularly during heavy rainfall events. Upstream sounding data is used to investigate how the properties of the oncoming flow affect rainfall predictability.

PRELIMINARY OPERATIONAL SATELLITE RAINFALL ESTIMATES IN THE MEDITERRANEAN COUNTRIES AND HYDROLOGICAL CONSEQUENCES

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An automated Meteosat satellite rainfall estimation technique that computes real time rainfall rates for flash floods watches and warning and heavy precipitation events (Vicente, 1997), is being applied for the Mediterranean countries and verifications against ground based rainfall data in Italy and SSM/I satellite rainfall observations are planned.
The estimates will be produced every half hour with a resolution of about 5 by 5Km. The METEOSAT longwave infrared (IR) channel is the primary data source, since it provides high temporal and spatial IR cloud top temperatures that allows the study of the temporal and spatial evolution of the cloud systems.

ROLE OF CLIMATIC INDEX IN GEOMORPHOCLIMATIC DERIVATION OF FLOOD FREQUENCY

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The climatic index and the SCS Curve Number method were used in the context of a procedure for the geomorphoclimatic derivation of frequency distribution of floods. The study was carried out for 8 catchments in Basilicata (southern Italy) with areas ranging between 42 and over 1600 Km^2 and heterogeneous climatic features. For these basins land use and geological data were obtained from a GIS. CN was calculated as a spatial weighted average value. For each catchment we selected a mean value and a range of CN obtained for different values of antecedent moisture conditions. Two significant behaviors resulted in the distribution on the CN values in the region. On one hand, CN was found consistently related to the distribution of the average number Λ of independent events for floods, resulting from an earlier regional analysis carried out in the same region. Since Λ shows in the region a clear dependence on the degree of aridity or wetness of the basins, a formal climatic index was determined for each basin.
Both Λ and CN showed significant correlation with the climatic index.
This relation is of notable interest when a physically based method for derivation of the flood frequency curve is used (Bacchi et al., 1992). Accounting for the average climatic configuration of basins allowed correct estimation of the mean and of the variance of annual maximum series of floods.

Utilizing rainfall models in an orographiqally complex territory such as Veneto Region.

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One of the most important questions concerning the application of rainfall fields given by weather models to the reality of the territory, also in relation to hydrologic forecast, is the influence of the mountains in areas characterized by a complex orography, such as Veneto Region.
In fact, the most of the models give large scale rainfall fields, which do not take into account the influence of orography, or take it into account in an approximately way.
In this work the effects of the orography of Veneto region are studied, through comparison between rainfall fields given by large scale models and data acquired by ground stations, in diffuse rainfall situations and in relation with some typical synoptic configurations.
The final goal is, considering the actual synoptic situation, to extrapolate rainfall forecast at a sub-regional scale from the large scale rainfall model, especially over mountainous zones which as known play a determining role in hydrologic forecast.

INFLUENCE OF MEASURING ERRORS DUE TO UNCALIBRATED RAINGAUGES ON FLOOD ANALYSIS AND PREDICTION

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After a wide surveys of operational raingauges was performed, both in meteo stations and in laboratory testing, on some 60 instruments in the Liguria region of Italy, the need of periodic checking using dynamic calibration was recently demonstrated (Lombardo and Stagi, 1997). Fourty of the raingauges analysed are currently used by the National Hydrographic Service in Genova, while the others are from private enterprises or different organizations. In the absence of official calibration curves the analysis of reliability of the device was checked at the meteo stations in the field, observing errors which range between 10-30% in the case of heavy rain rates. After cleaning in laboratory the typical error of this homogeneous class of raingauges lies around 10-15%. Rainfall variability during storms produces larger errors with increasing rainfall rates within suitable integration intervals. The effect of the error variability on any conceptual approach to the modeling of rainfall-runoff processes is hard to be predicted due to the non-linearities involved. In this paper a simple model is used to test the influence of rainfall measurements obtained from uncalibrated raingauges on flood analysis and prediction, using the actual calibration curves for correction of the measured values.

STORM STRUCTURE VARIABILITY IN HISTORICAL RAINFALL RECORDS OBSERVED IN ITALY

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Some long daily rainfall series observed in Italy are analysed in order to detect the variability along time of the storm structure. Accordingly, the available rainfall records, which are at least 80 years long, have been split in non-overlapping blocks, each one collecting 10 years of data. Then, a Neyman-Scott Rectangular Pulses rainfall model has been fitted on each block. The Neyman-Scott model applied, which has monthly parameters, is characterised by two types of rain cells, a convective one and a stratiform one. Parameters fitting has been carried out minimising the squared differences between some statistical properties of the model and the corresponding statistics computed on the historical record. The minimisation has been obtained applying the simplex algorithm. The analysis of the time variability of both the model parameters and some basic statistics of the daily data, such as the mean the variance and the proportion of dry periods, allows to assess the variability along time of the storm behaviour.

IMPACT OF GLOBAL CLIMATE CHANGE ON ELEVATION ZONE PRECIPITATION STATISTICS

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A stochastic approach is developed to estimate the effect of global climate change on daily precipitation statistics over three catchment elevation zones (upper, middle, lower). The probability of daily precipitation occurrence and distribution of wet and dry period duration as well as the mean and standard deviation of daily nonzero precipitation are analyzed. The approach is based on the analysis of daily atmospheric circulation patterns (CPs) and the linkage between types of CPs and daily precipitation. Three CP data sets are used for the 500 hPa pressure field : 40-year historical, 10-year $1\times CO_2$, and $2\times CO_2$ scenarios obtained from the general circulation model of Max Blanck Institute. Nine CP types for the winter and summer half years are obtained to characterize large-scale climatic forcing in Mesochora catchment in Central Greece. Under the continental climate of Mesochora mountainous catchment the effect of $2\times CO_2$ scenario on elevation zone precipitation regime is variable and significant: the probability of daily precipitation slightly increases , while significant changes are detected in the distributions of wet and dry period durations. Both the mean and variance of daily precipitation decrease significantly during the summer season.

SPACE-TIME MODELLING OF RAINFALL IN FINE INTERVALS: THE "STRING OF BEADS" MODEL

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A scheme is proposed for modelling and simulating sequences of rainfall intensities (or depths) over an area covered by a radar (typically 200 km in diameter) to a resolution of 1 km square, in small time intervals. The model has two components: a univariate generalized point process model which alternates dry with wet periods and a space-time model which describes the evolution of the wet periods in time and space. The marginal distribution of the rainfall amounts on each CAPPI (Constant Altitude Plan Position Indicator) is modelled by a censored lognormal distribution. The univariate point process model is similar to a shot-noise model. Once initiated, the rainfall events (storms) themselves are modelled in space-time using transformed filtered white noise mimicking the statistics of observed storms. The 3-dimensional (space-time) development of a storm follows once the duration and type of storm is defined by the point process sub-model:- white noise is generated in each cell of a 3-dimensional box with two space dimensions and one time dimension; - the box of white noise is Fourier transformed, power-law filtered in frequency space (assuming appropriate scaling in all dimensions) and reverse transformed to space-time - the correlated noise is then exponentiated and scaled to the desired average rainfall depth and thresholded at 1mm/hr to give the correct proportion of dry patches on each of the sequence of CAPPIs in a storm event - the model is designed to drift the "storm" over the area at a chosen velocity, by moving the successive frames by the right number of pixels in any direction. The result "looks" like rainfall and has the right statistics.

AN IMPROVEMENT OF WEATHER RADAR ESTIMATION OF RAIN CLASSIFYING RADAR RAINFALL ESTIMATIONS INTO CONVECTIVE AND STRATIFORM

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Weather radar estimates the rain intensity (R) indirectly through measurements of reflectivity (Z) of an elevated volume aloft from the ground. This estimate is afected by a well known number of source of errors. One of them is the variability in the drop size distribution that implies different parameters in the Z-R relationships. A usefull prior classification might be the distinction between convective and stratiform Z-R relationships. This distinction is based on the fact that vertical motions and microphysical growth mechanisms of the precipitation are very different in the clouds that generate each type of rain. In this way, stratification of radar echoes from rain into convective and stratiform regions could lead to an improvement of radar rainfall estimations. The present study evaluates classification techniques designed for this purpouse. Data sets from Montreal and Barcelona that include the two types of precipitation were used. The classification criterea were centered into two aspects: a) the identification of the bright band, a clear signature of the stratiform precipitation related to the melting near the 0° C level, using the vertical structure of the radar echoes and b) the identification of the convective areas using the horizontal structure of the radar echoes.

NOTE ON HEAVY PRECIPITATION

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The study of heavy precipitation has long been a subject of particular interest to both meteorologists and hydrologists. The problem is complicated by the fact that precipitation may have many forms and causes. Nonetheless, a number of attempts to describe the various types of precipitation by means of a single, simple equation have been made in the past. In the early 1950's, for instance, Fletcher found a widely accepted empirical equation, based on data from around the world, which shows the relationship between the duration of an event causing extreme amounts of rainfall and the upper limit of the resulting depth of the precipitation itself. In order to confirm and better understand this formula, Kahlig examined Fletcher's result by means of dimensional analysis. This method seems to be highly suited for the problem at hand, since a satisfactory result can be obtained relatively easily if the choice of parameters required for the equation is correct. It appears, however, that Kahlig's approach might only apply to part of the problem, namely precipitation caused by convection. In this study, an alternate approach, also using dimensional analysis, is presented, in which the transport of water vapor is examined. Although the parameters used herein are different from those suggested by Kahlig, the validity of Fletcher's equation can again be confirmed.

EXTREME RAINFALL AND DIMENSIONAL ANALYSIS

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Dimensional analysis has long been used to explain complex problems in the fields of Physics and Meteorology. One area where this technique can be applied is in examining empirical or semi-empirical physical relations. One problem which has thus far not been completely explained is the connection between the depth of extreme rainfall and its duration. Fletcher was able to find an empirical equation describing this relationship almost fifty years ago. This formula has been widely used by scientists in hydrometeorology. Recently, Kahlig investigated the problem of extreme rainfall using dimensional analysis, and his results appear to confirm Fletcher's formula in a highly convincing way, assuming that the parameters suggested by Kahlig are valid. In this paper, the problem is examined in greater detail, again by means of dimensional analysis. Specifically, both convective and non-convective cases are examined. Whereas Kahlig's results, focusing on the role of a turbulent diffusion coefficent, seem to consider only the convective case, the role of the water vapor in the air above a surface is now considered. The results, combined with those of Kahlig, seem to show that Fletcher's equation can be applied to both convective and non-convective precipitation.

Non-linear statistical modeling of runoff using MARS

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The forecasting of runoff is essential for an efficient management of hydrologic projects. With this purpose, a statistical model was developed to estimate daily flow at Aguieira dam (Portugal) from daily precipitation, measured at Coimbra (about 30 km west). The data cover the months November to March, from 1984 to 1994. November was chosen for the beginning of each annual period to allow the settling of the autumn-winter precipitation regime and the quasi-saturation of the soil.
A regression function for each one of the November-March periods is developed applying MARS technique, using as predictand the difference between consecutive runoff values and as predictors daily rainfall values relative to the precedent five days. Ten models are then obtained, and each one is validated using the remaining nine annual periods as independent data. Finally, a forecast value for runoff is proposed, based on the average of the regression functions' results that were obtained for calibration periods with normal-to-high precipitation.

A STOCHASTIC MODEL OF RAINFALL AT THE RAINDROP SCALE

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Rain rate fluctuations observed with different types of ground-based instruments (spectrometers, disdrometers and rain gages) reflect not only the intrinsic properties of the rainfall process itself, but those of the instruments as well. In order to study the relative influence of the spatial and temporal resolution of the various measurement devices on the observed rain rate variability, we have developed a simple model for the raindrop arrival rate based on stochastic point processes. The interesting property of this doubly stochastic Poisson process model is that it considers individual raindrops. We will present both analytical and simulation results of the modeled fluctuation properties associated with the mentioned instruments. Moreover, a comparison of model results with actual rainfall observations from an optical spectrometer will be presented.

NH2 Meteorological and hydrological hazards (co-sponsored by HS)

01 Uncertainty assessment in meteo-hydrologic warning

Convener: Todini, E.
Co-Convener: Castelli, F.

UNCERTAINTY PROPAGATION IN RAINFALL-RUNOFF MODELS

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A numerical procedure to propagate rainfall and parameter uncertainty through rainfall runoff models is presented. The method takes a numerical sample of the rainfall input PDF and model parameters PDF and governs the downstream uncertainty propagation through a network of model components. Each model component receives multiple input and generates multiple output through a combination of rainfall and parameter alternatives. Hydrograph combination is performed at connecting elements, where the number of alternatives is reduced to a manageable size. Three selective criteria may be applied to prevent the combinatorial explosion as the information flows downstream: synthesis, similarity and relevance. A numerical experiment to test the validity of the proposed model is presented.

COMBINING LIMITED AREA MODELS QUANTITATIVE PRECIPITATION FORECASTS WITH GROUND MEASUREMENTS

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During flood events decision makers must take decisions under the uncertainty of future events. It is therefore necessary to provide not only a forecast, but also an estimate of the probability distribution of forecasted discharges. Given the non-linearity of the rainfall-runoff processes, this is generally done by generating future realisations with stochastic models of precipitation and by transforming these precipitation traces into runoff with the appropriate hydrological models.
In general the stochastic generation of future rainfall tends to depict a very uncertain future with a standard deviation of the distribution which rapidly increases with the lead time.
Recently, meteorological Limited Area Models (LAMs) are being extensively used to produce quantitative precipitation forecasts (QPFs). Unfortunately at present, LAMs still provide QPFs with a large degree of uncertainty, although this uncertainty does not depend on the forecasting lead time.
The first step of this work was to assess the quality of the LAMBO (a LAM operationally used in Emilia Romagna):.the forecasts were compared to the values measured using a dense raingauge network on the Reno river and biases as well as error variances were derived.
Successively, after generating a set of future precipitation traces by means of a stochastic nearest neighbour approach, the deterministic LAM forecast was used as a biased and uncertain measure of the future rainfall occurrences, within the frame of a Kalman filter scheme, to correct the a priori generated series.
The results, which show interesting properties in terms of bias reduction as well as in the reduction of the uncertainty, may be operationally used to provide the required discharge forecasts together with an estimate of their distribution.

A STATISTICAL METHOD FOR DESCRIBING UNCERTAINTY IN FLOOD FORECASTS FROM A HYDROLOGICAL RAINFALL-RUNOFF MODEL BASED ON METEOROLOGICAL FORECASTS

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The uncertainty associated with a flood forecast is important for risk assessment and useful in the decision making process. For example, the probabilities of exceeding certain critical levels may be more informative for a decision maker than the expected flood. Therefore, it is useful to quantify this uncertainty and incorporate it as part of the forecasting routine. For flood forecasts based on a rainfall-runoff model, the calibration error of the rainfall-runoff model and the effect of uncertainty in the meteorological forecasts are taken into account. A statistical model is fitted to two years of simultaneous values of the 1-6 days ahead forecasts of temperature, precipitation and runoff for two catchments in Norway. The calibration error of the rainfall-runoff model is estimated from 10 and 40 years of daily observations from the same two catchments. Our analysis indicates that the forecast errors are approximately proportional to discharge, and have an autocorrelated structure. An autoregressive model was fitted to each catchment, with stratification on temperature, precipitation and snow cover. The resulting model gives prediction confidence intervals given meteorological and hydrological forecasts. We illustrate the use of the model on a verification data set.

DOWSCALING OF RAINFALL PREDICTIONS AND UNCERTAINTY IN THE ASSOCIATED FLOOD EFFECTS AT THE GROUND

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One major concern in the operational use of rainfall predictions obtained from numerical meteorological models is that forecasting is provided in terms of integrated quantities over a resolution grid of the order of 100 km in space and 3/6 hours in time. In all cases where the catchment size is smaller than the model resolution in space, and consequently the hydrological response time is shorter than the resolution in time, some downscaling of rainfall predictions is required. This involves introduction of additional uncertainties with respect to those already present in the meteorological prediction chain, due to the structure and parameterization of the mesoscale models used. Following the downscaling exercise, distributed hydrological rainfall-runoff models can be used to determine the expected flood peaks in all catchments that are covered by the predicted rainfall field. Some preliminary results are presented about the downscaling of rainfall predictions obtained by LAM, using a simple algorithm based on the separation of the rainfall fluctuations in space and time. Fluctuation in space are synthetically generated in the form of a Gaussian bi-dimensional field with zero mean, unit variance and specified correlation structure. The correlation in time is derived from that in space in the hypothesis that the coherence of scale in the outcoming rainfall field is preserved. Results of the simulation of the extreme precipitation event observed on September 1992 over western Liguria (Italy) are presented in terms of flood peak estimates.

A STOCHASTIC APPROACH TO SPACE-TIME RAINFALL FORECASTING

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The MTB stochastic space-time rainfall model has been developed for generating ensemble forecasts conditioned on radar images. The MTB model is continuous over space and time, and reproduces the features of observed rainfall fields at four distinct scales: raincells, cluster potential regions, rainbands and the overall outline of a storm at the synoptic scale. An inversion procedure has been developed for inferring a construction of the MTB model from a given sequence of radar images. This procedure is then used to generate ensembles of future rainfall scenarios for various time origins which are consistent with a currently observed storm. The ensembles are converted into ensembles of flow forecasts for the Brue catchment in South-West England, to demonstrate the feasibility of the approach for real-time flood forecasting.

NH2 Meteorological and hydrological hazards (co-sponsored by HS)

02 Prediction of hazardous events of meteorological origin

Convener: Tibaldi, S.
Co-Convener: Alonso, S.

UNCERTAINTY ASSESSMENT OF EXTREME RAINFALL FORECAST

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Meteorological quantitative precipitation forecast (QPF) models are promising techniques for improving hydrological real time forecast performance. The usual assumptions underlying QPF models do not allow to easily deal with the evaluation of predictive uncertainty. Arbitrary distributional assumptions are often induced in the model in order to achieve this purpose. At the present time, a suitable alternative is offered by hydrological precipitation forecasts obtained by stochastic models based on rain-gauge network records or weather radar image. Bayesian forecasting offers a natural approach to the evaluation of predictive uncertainty. The procedure requires the specification of a likelihood function and a prior distribution for the predictions. The posterior distribution is then evaluated recursively from the data as new observations become available. A measure of uncertainty is generated via the estimation of posterior distributions for predictions. Practical operational hydrologic models usually deal with areal precipitation forecasts obtained from areal or multisite observations. For this purpose the previously mentioned procedure must be associated with a technique for the spatial aggregation. The present work mainly regards the former step. In order to illustrate the procedure, an application to rainfall data recorded in a dense rain-gauge network located in Arno basin is presented. Particular attention will be payed to the analysis of very extreme events (outliers), typical of mediterranean regions.

NH2

NEURAL NETWORKS FOR DATA QUALITY CONTROL

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The understanding of data on atmospheric processes requires ever new handling techniques in order to cope with the large amount of complex information collected by direct and remote sensing measurement systems. The growth of automatic instruments capable of unsupervised operation simplifies the collection of these data and their storage, but the data end up in memory without having undergone checking. The restoration of an incomplete time series of data and the resolution of the outliers present many difficulties and there are just a few methodological proposals on this topic. The present research illustrates the use of a neural network in data quality control and reconstruction. The approach consists of training through a back propagation supervised procedure a neural network of fixed architecture, comparing real to virtual data produced by the network. Neural networks are applied to the problem of interpolating and extrapolating daily maximum temperature as well as to nowcast of tropospheric ozone concentration values. Different network architectures are explored and applied to a number of time series of data measured in different places and/or in different time periods. Observed and predicted data are compared to test the efficacy of neural algorithms in predicting environmental processes. To understand the operation of neural networks it is useful to work with simplified network architectures. As an example, results are reported using networks with only one input neuron, one hidden layer with three neurons, and one output neuron. The results presented show that neural models not only represent an efficient alternative to classical models, but also allow improvements in data quality control and in short term forecast.

SENSITIVITY EXPERIMENTS ON THE RESPONSE OF LAND SURFACE WITH THE COUPLED MODEL RAMS-LSPM.

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A coupled model of RAMS mesoscale model (version 3b) and a well-developed land surface processes model (LSPM, version 3.0) has been established. The aim of this work was to improve the regional water balance representation, in order to reproduce the regional climate in a more accurate way.
The important elements for regional water balance such as precipitation, evapotranspiration, surface runoff, infiltration and bottom drainage processes have been included in the coupled model. Some sensitivity experiments to soil and vegetation parameters (such as soil type, initial soil moisture content, vegetation coverage, minimum stomotal resistance, leaf area index and canopy resistance) have been done, and the results have been simultaneously compared with the ones of the original RAMS3b surface model. The results show that the coupled model RAMS-LSPM produces more realistic estimates of the apportionment between sensible and latent heat fluxes with respect to the original surface scheme.

SIMULATION OF A SEVERE WEATHER EPISODE IN PIEDMONT (3-5 NOVEMBER 1994) USING THE COUPLED MODEL RAMS-LSPM.

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A coupled model of RAMS mesoscale model (version 3b) and a well-developed land surface processes model (LSPM, version 3.0) has been established. This coupled model has been used to simulate a severe weather process which leads to the disastrous flood in north Italy during 4-7, Nov., 1994, simultaneously compared with the observations and the original version of RAMS3b. The geopotential, the stream lines and temperature and humidity fields are represented almost equally by the new version RAMS3b and by the old one. On the contrary, the differences of the land surface sensible and latent heat fluxes are large, and this fact causes a considerable differences between the the precipitation calculated by the two versions. The main differences exsists in the response of soil to the precipitation. The soil moisture of the old version RAMS3b never saturates under the strong input of precipitation, while in the coupled model the soil has been saturated for one day causing strong surface runoff, which constitutes the flood.

USING PROBABILISTICS DISTRIBUTION IN A REAL TIME FLASH FLOOD FORECASTING SYSTEM

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Efficient flood warning in rural catchments requires lead-times of at least 6 to 12 hours, while nowcasting in mountainous regions cannot provide forecasts beyond 1 or 2 hours ahead. So the flood forecaster should use as input to his hydrological models rainfall scenarios which may be derived by different techniques.
Our first aim was to build a rainfall generator conditioned by the immediate observed past while respecting the climatological structure of storms. Next this paper shows that conditioning by the expected future is fruitful. Here the forecast used is expressed as the conditional distribution of the daily totals expected over a fixed time window. Moving from the current day to the next can be smoothly managed by using progressively a mixture of the forecast for the current day, partially elapsed, and of the forecast available for the next day.
An example is displayed on the upper part of the Ardèche river basin (121 km^2). It is shown that using the future for scenarios is more informative that using only the immediate past, in terms of discharge forecasting.

FROM FLOOD FORECASTING TO REGIONAL WARNING.

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The morphology of the Northern Mediterranean coastline is made up by small-medium catchements (10-1000 km^2) historically developed by a number of villages and cities. Final flood plains had been developed in the past centuries by reducing braided riverbeds into narrow channels which design was based on the past centuries hydrological experiences. By this reasons inundation events of historical city centers are very frequent and proper civil protection policies require to issue during the flood season early warning messages to risk exposed population. Space and time scales of the available meteorological deterministic models exceed the size of most catchements. To quantify the uncertainty of the rainfall inputs is quite difficult. Past decade extreme events evidence over the Liguria Region is presented. Events are described by LAM outputs, Meteosat images and ground observations. Coherence between predictions and ground effects of rainfall events is also discussed. Experimental evidence suggests that robust methods are required to estimate in advance risk conditions leading to early warning diffusion. The space scale of Ligurian watersheds and the inherent meteorological inputs uncertainty require to target to ample subregions the early warning. A few examples of true and false alarms are finally discussed.

UNCERTAINTY ASSESSMENT IN THE PREDICTION OF EXTREME RAINFALL EVENTS: AN EXAMPLE FROM THE CENTRAL SPANISH PYRENEES

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Extreme pluviometric events are very unfrequent in time and very erratic in space. In general, they affect few square kilometres in their most active part, as several catastrophic rainfalls have demonstrate (i.e. the flood in Biescas, August, 7, 1997) and their identification in meteorological data.series is very difficult As a consequence, it is almost impossible to make an accurate prediction of extreme events using the traditional statistical procedures. The irregularity is even greater in mountain areas, where a complex topography encourages the generation of isolated rainstorms. In this paper the application of the Gumbel formulae to a dense rain gauge network (in the Central Spanish Pyrenees) confirms the impossibility of predicting the most hazardous areas: In fact, for a given expected precipitation in 24 hours, the predicted return period can oscillate several magnitude orders even in places located less than 20 kilometres apart.

THE USE OF ARTIFICIAL NEURAL NETWORKS OVER THERMODYNAMIC DATA FOR EXTREME RAINFALL EVENTS CLASSIFICATION AND FORECASTING

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The knowledge about the data obtained from the radiosounding ascents are essential for the forecasting, analysis or diagnostics of weather. Particularly the atmosphere's thermodynamic analysis makes it possible to obtain information about the possible existence of instability or about an auspicious environment for convection, the contents of water vapour as well as the possible formation and development of clouds. and the existence of wind's shear and jet streak. The thermodynamic analysis has a highly discriminating feature in those situations in which the synoptic situation does not allow to completely justify either the atmospheric phenomena nor their distribution. On the other hand, artificial neural networks represent an emerging technology rooted in many disciplines. They are endowed with some unique attributes: the universal approximation and the ability to learn from their environment. The objective of this presentation is to show the use of artificial neural networks over thermodynamic data for extreme rainfall events classification and forecasting in Catalonia, Spain, using the radiosounding ascents of Palma de Mallorca since 1975 until 1989. We have tested different inputs (precipitable water mass, equivalent potential temperature, CAPE and so on) and different learning processes. The results obtained have allowed to select the most representative variables and to classify the different rainfall events in relationship with the thermodynamic variables.

USE OF THE REANALYSED DATASET OF THE NECP/NCAR TO IMPROVE DAILY QUANTITATIVE PRECIPITATION FORECAST BY AN ANALOGUE TECHNIQUE

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The NCEP/NCAR reanalysis project has produced a 40-year (1955-1995) record of global analyses of atmospheric fields, through the same model. It offers very interesting perspectives for forecasting methods based on analog techniques, because they are mainly reliant on the length, the homogeneity and the fullness of the historical data file. That's why these re-analysed dataset is being tested in a daily quantitative precipitation forecast method using analog situations sorting out. The analogy criterion, initially a simple Euclidean distance, has been successfully replaced by the Teweles-Wobus score applied on 700 and 1000 hPa geopotential fields. But these fields, stemming from Electricité de France and Météo-France, are not very homogeneous because they have been modified every time the meteorological model has changed.
So, at first, we will present significant results obtained by changing the analogy criterion into the Teweles-Wobus score. Then, these results will be compared with those obtained with the same geopotential fields (700 and 1000 hPa), but reanalysed by the NCEP/NCAR. And finally, we will also try to enter, in the analogy criterion, new information from the NCEP/NCAR dataset, like humidity at low level, high geopotential fields, potential vorticity, wind ...

NUMERICAL SIMULATION OF HEAVY PRECIPITATION EVENTS USING TWO DIFFERENT VERTICAL COORDINATE SYSTEMS

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In the framework of the MAP (Mesoscale Alpine Program) project numerical simulations of intense precipitation events in the Alpine Region have been carried on. The model employed is LAMBO (Limited Area Model Bologna), which is based on a version of the Eta (NCEP) model and is operational at the Regional Meteorological Service of Emilia Romagna (ARPA - SMR). Apart from the sensitivity to horizontal resolution, the numerical simulations were mainly addressed to investigate the impact of using two different systems of vertical coordinate: the usual terrain-following sigma and the quasi-horizontal eta. The analysis of the results has been focused on the details of precipitation forecast but also on the 3d structure of the flow over and around the mountains, which appears to be very sensitive to the vertical coordinate used.

NH2

SYNOPTIC AND MESOSCALE DIAGNOSIS OF A HAILSTORM SITUATION IN EASTERN SPAIN

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On 4 September 1995, several convective cells developed inland of eastern Spain during the afternoon. As these storms grew and moved toward the Mediterranean Sea, a hail event occurred during the evening in the Valencia region. Hailstones attained diameters of up to 7 cm, and the resulting losses in the grape production of the affected area were very important. The meteorological situation was characterized at upper levels by a deep trough that evolved over the Iberian peninsula. The associated low-pressure centre at low levels absorbed and intensified a preexisting relative low off the eastern coasts of Spain. Synoptic ingredients favourable for deep convection have been identified over the area where convective cells developed. An investigation of the mesoscale features reveals the existence of a low-level convergence line over eastern Spain produced by the aforementioned pressure lows, and a dry cold air tongue introduced into the Mediterranean from the north by a Genoa Gulf low pressure centre. Satellite pictures show the presence of two jets at two different levels of the upper troposphere, which ageostrophic circulations favour the convection development.

DEVELOPING VERSUS NON-DEVELOPING CONVECTIVE VORTICES INTO "HURRICANE-LIKE" CYCLONES OVER THE MEDITERRANEAN SEA

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Beyond the more common, baroclinic, orographically induced lee-cyclones, a different category of sub-synoptic scale vortices, dominated by intense convection, has been documented in the Mediterranean in late summer, fall and early winter. Some of these vortices develop a "hurricane-like" structure. Dynamics and classification of these vortices are discussed by O. Reale (OA12 session).
In this presentation, two years of the National Center for Environmental Predictions (NCEP, USA) Medium Range Forecast (MRF) model's output are analyzed: 1996 and 1997, emphasizing the 48 and 72 hour forecast. During this period, 4 sub-synoptic vortices with a hurricane-like structure were detected. They were all correctly predicted, but the model forecasted the insurgence of 5 other events which actually did not develop a hurricane-like structure.
In this study it is shown how some dynamical criteria adopted for the Tropical regions to distinguish between developing and non-developing convective vortices, can be successfully applied in the Mediterranean, thus reducing the over-forecasting error in the NCEP model. Particularly, barotropic instability is an important source of energy, wehereas baroclinic instability acts as an inhibiting mechanism: their evaluation in the model's output represents a good predictor.

NUMERICAL SIMULATIONS OF INTENSE PRECIPITATION EVENTS USING THE ETA MODEL

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During recent years the Alpine region was affected by several intense precipitation events which caused serious damages and loss of human lives. In this respect it is of crucial importance the correct meteorological forecast of the events which can be the cause of potentially dangerous situations. The Alpine region and the Mediterranean area in general present features that can heavily influence the local atmospheric flow and the related phoenomena. The occurrence of heavy rain over small regions should require synoptic scale and mesoscale conditions favourable to the development of persisting upward motions and moisture convergence.
In the framework of the international MAP project (Mesocale Alpine Programme) some events of the kind described above were selected and are currently object of intensive study, also using numerical models, in order to understand in details the features of the related atmospheric flow. Therefore, simulations of some of these episodes using a mesoscale operational model were performed and the results will be shown, with particular attention to the quantitative precipitation prediction. The model used is the Eta model, version 1993, which is operational at NCEP, USA. Comparisons with ECMWF analysis and with observed precipitation data will also be shown.

HEAVY PRECIPITATION QUANTITATIVE FORECAST: A COMPARISON BETWEEN MEASUREMENTS AND LIMITED AREA MODELS OUTPUTS.

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Heavy precipitations may frequently occur in all mediterranean area, particularly in regions with a steep and complex orography like Liguria. These precipitations caused flash floods with life and property losses. The severity of some of those recent events justifies the research efforts aiming at improving quantitative rain forecasts. The forecast accuracy of heavy precipitation and flood hazards is obviously associated with the skill of rainfall forecast in space and time. It is well known that atmospheric General Circulation Models (GCMs) provide precipitation fields which, at a resolution not suitable for weather and hydrological predictions in areas with steep orography, mostly because of small-scale phenomena caused or triggered by orographic response. Therefore, for regions with a complex and steep orography, like Liguria, the use of a very high resolution model is needed.
Our aim is to compare forecasted and measured rain for a set of events characterized by heavy precipitations in the Ligurian Region, most of them causing floods. To do this we compared distribution patterns of precipitation values forecasted by Limited Area Models operating at different resolutions.

NUMERICAL SIMULATIONS OF THE VAISON LA ROMAINE FLASH FLOOD

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Numerical simulations with the nonhydrostatic anelastic model Meso-NH are carried out to reproduce the flash flood which occurs in the city of Vaison la Romaine. This flood is the result of several mesoscale convective system which develop ahead of a cold front in the southern part of the Alps. In many aspects, this case appears as a prototype case for the preparation of the MAP (Mesoscale Alpine Program), which will study convection on the Alps as one of its main purpose. Meso-Beta and meso-Gamma scale phenomena will be discussed with the help of nested simulations, using meshes equal to 20 and 2.5 kilometers. Quantitative comparison with rain gauge and radar observations will be used to validate the simulations. Then, the orographic and sub-synoptic influences (cut-off low and streamer) will be analysed for the convection triggering in both simulations in order to understand this complex case.

STUDY ON THE ROLE PLAYED BY A MINOR MOUNTAIN CHAIN IN TRIGGERING DEEP CONVECTION

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Numerical Weather Prediction models allow the investigation of the interaction of the atmosphere with mountain chains. It is well known that warm and moist overrunings and low-level moisture flux convergence can be strongly amplified by orography, with large increase of precipitation as a consequence. Moreover, vertical motion and convection can be triggered and enhanced by orography. All these events, but particularly the latter, are obviously underestimated by General Circulation Models, which cannot describe the spatial variability shown by precipitation fields over areas in which the orography scale displays a high spatial frequency. Therefore, for regions with a complex and steep orography, like Liguria, the use of very high resolution models is needed.
In order to evaluate the effect of a minor mountain chain (the Apennines, Italy) on the atmospheric mesoscale flow, a simulation of some extreme events, that affected the western Mediterranean producing high precipitation amounts and floods over Liguria (Italy), have been performed with the Limited Area Model (LILAM) operationally used to make weather forecast in our centre. The aim of the present work is to investigate the role played by a minor chain in modifying the small scale atmospheric flow, with emphasis on the role played in triggering deep convection.

OPERATIONAL USE OF REAL-TIME FLOOD FORECASTING

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Following a brief overview of the state of the art in real-time data acquisition and flood forecasting, this paper aims at presenting a number of real-time flood forecasting and warning systems, operationally installed in Italy as well as in Germany and in China, based upon the European Flood Forecasting Operational Real-Time System (EFFORTS) originally developed at ET&P on behalf of the Commission of the European Communities.
Problems encountered and the use of forecasts in the decision making process aimed at reducing the risk due to flooding, will be discussed. Finally, a recent example of application for the management of lake Como in Italy will be presented. In this application real-time flood forecasting is combined to a real time stochastic optimisation algorithm in order to increase the expected value of benefits deriving from the use of waters (irrigation and hydro-power) while reducing the expected damages due to the flooding of Como main square.

NH2 Meteorological and hydrological hazards (co-sponsored by HS)

03 Flood hazards and flood risk: regional analysis of extremes (co-sponsored by OA)

Convener: Bois, P.
Co-Convener: Oancea, V.

FLOOD PREDETERMINATION MODEL BASED ON HOURLY RAINFALLS STOCHASTIC GENERATION

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For the needs of hydrological studies, a hourly rainfall stochastic model has been developed to be coupled with a rainfall runoff conversion model. Thus, many hourly flood scenarios are obtained by simulation on very long periods. The hourly rainfall model has been improved and tested on a large area, 49 raingauges located on the French Mediterranean seaboard. With the rainfall generated, flow time events are simulated with the conceptual spatially-lumped model GR3H. The method has been tested on 17 watersheds on the studied area and gives good results. The advantage of this approach is to obtain rainfall and runoff temporal information. Different realistic flood scenarios, which occurrence is obtained by simulation, are used instead of a unique design flood. Moreover, the large use of rainfall information and the rainfall runoff conversion modelling seems to give a more important stability to this approach rather than the classical statistic methods.

THE FREQUENCY OF LOW MAGNITUDE FLOODS: A STUDY OF THE RELIABILITY OF THE ANNUAL MAXIMUM SERIES METHOD

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The analysis of annual maximum series is a standard procedure used to establish the recurrence of floods of a given magnitude; however, it ignores subordinate peaks of some years which exceed the lowest maxima of the series, and thus underestimates the occurrence of low magnitude floods. To determine the reliability of the AMS method, frequency distributions of low magnitude floods derived either from annual maxima (AMS) or from all peaks exceeding a selected threshold discharge are compared for a set of gauging stations located in the upper Vistula River drainage basin, but on streams with somewhat different flood regime and a range of catchment areas. A considerable variation in the mutual relation of the two series exists among the stations despite their close proximity. The high variation remains even when the recurrence intervals of the AMS are transformed to their equivalents in the partial duration series by means of the Langbein relationship. The divergence between the AMS and PDS increases with growing variability of the annual maximum discharges, and generally, the underestimation of flood discharges of a given recurrence interval by the AMS is high for streams with a flashy regime, but low for streams with more uniform run-off. This study shows that the actual flood magnitudes for a given probability cannot be satisfactorily obtained by means of a simple transformation of the recurrence interval for known AMS discharges. Therefore, despite the long tradition of using the AMS method, it is recommended that the partial duration series method should be employed when evaluating the occurrence of low magnitude floods.

LAST YEAR SUMMER FLOODS IN MORAVIA: WHAT IS THE FUTURE?

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Dramatic floods occurred in Central Europe in summer 1997, Czech Republic being afflicted especially in its eastern part - Moravia. Predictive approach when modeling flood recurrence may be helpful in flood management. Summer floods are typical by saturated catchment due to long-lasting heavy precipitation followed by an extreme rainfall. We analyzed temporal variability of precipitation time-series by fractal analysis, revealing persistent fractional noise with dimensions of 1.3-1.4. Precipitation appears to be a random small amplitude fluctuation superposed on a background controlled by more regular quasi-cycles. While the individual up-down runs last 3-5 years, the persistent trends may take more than 15-30 years. The precipitation character in Moravia, being declining with a rate of 2-5 mm/yr during the past 30-35 years, changed suddenly to the opposite tendency following the dry period of 1992-94. We modelled precipitation fluctuations with the Mandelbrot's fast fractional Gaussian noise tecnique. Simulations were used for stochastic prediction of the precipitation trends causing summer floods. Our results seem to give evidence that higher precipitation in the last years is not a sort of provisional run but belongs to a persistent trend.

REGIONAL ESTIMATION OF HIGH INTENSITY SHORT DURATION RAINFALL EVENTS

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The procedure for regional estimation of excess probability has been applied to high intensity short duration rainfall events in order to evaluate the flood hazard in Ligurian catchments. TCEV - Two Components Extreme Value - probability distribution has shown excellent descriptive and predictive capabilities, as compared with usual EV probability distributions. The determination of scale parameter has been performed by linking ground observed historical data with remote sensing observation of the typical extreme storm structure over the region. The observed variability of the scale parameter across the region suggests that the maximum annual short duration rainfall depth process has its central measure controlled by a simple physics. Convective processes over Liguria region are mainly driven by orographic uplift: the relative angle between the southern slope of the Ligurian Apennines and the direction of largest S-N fetch seems to control the intensity of deep convection. Experimental evidence is presented

A METHODOLOGY FOR THE ESTIMATION OF THE IMPACTS OF CLIMATE CHANGE UPON FLOOD FREQUENCY (WITH UNCERTAINTY)

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A modelling strategy, appropriate to the assessment of the impacts of climate change upon flood frequencies within an uncertainty framework, is introduced. The methodology couples a stochastic rainfall generator with the frequency version of TOPMODEL for the purposes of flood frequency estimation. Following constraint of *non-behavioural* rainfall realisations through the application of an observed/simulated sum of absolute errors criterion (based upon duration class annual maximum rainfalls), multiple realisations of potential annual maximum flood frequency curves are produced through the use of continuous simulation and Monte Carlo techniques. Further constraint of these realisations is then achieved via an observed/simulated flood peak sum of absolute errors measure, low flow conditioning, and calibration/validation for continuous rainfall/runoff modelling. Uncertainty in the flood frequency predictions is estimated using these ***behavioural*** realisations within the Generalised Likelihood Uncertainty Estimation (GLUE) framework. Example applications are provided for assumed "stationary" conditions.

REGIONAL INCREASE OF WINTER FLOODS IN SOUTHWEST GERMANY CAUSED BY ATMOSPHERIC CIRCULATION CHANGES

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Instationarity in the time series of annual peak flow will be demonstrated for the Enz River Basin/Black Forest (A = 1 477 km^2), the upper Danube (A = 1 320 km^2), and the Nahe River Basin (A = 2 382 km^2) in Southwest Germany. The reason for this is a dramatically increase in frequency and persistence of the large scale atmospheric circulation type "West cyclonic" (Wz) for the wintermonths (Dec.-Feb.). During the observation period (1926-1997) nearly all extreme floods including the floods of Feb. 1990, Dec. 1993, and Jan. 1995 for all three Basins have been caused by weather type "Wz" during winter. Nonparametric tests show that instationarity starts for the winter-Wz-frequencies and the annual peak flows of the ENZ River, the Nahe River, and the upper Danube Basin in the period of 1972 -1977. By this a shift to an increased flood risk will be demonstrated for the three river basins. Instationarity of the peakflows is caused by a significant increase of winter precipitation which itself is caused by changes of the atmospheric circulation. This leads to the HYPOTHESIS: "If the frequency and persistence of the circulation type "Wz" will become stabilised on the actual high level, many river basins in hilly regions of Southwest Germany will have a dramatically increased flood risk." Instationarity does not concern all Germany, but it is a serious regional problem for many river basins of Southwest Germany

The influence of the local catastrophical phenomena in the atmosphere.

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It is well-know that the concentration of the harmful substances in the atmosphere sharply changes during catastrophical phenomena which results in the further alteration of the regional and then global climate. Due to such phenomena as shower- type precipitations, intence rains heavy showing, the atmosphere clears from the harmful substances but at the same time there is a peculiar pollution of the soil, rivers, lakes and then seas and the oceans in the given region. Strong winds which disperse harmful substancesfrom the given region ovev the large territories are also of great importance. In order to study the given problem statistical data of the meteorological valuea for the last 15 years on the territory of Georgia will be analysed using 30 meteorological station.

COMPARISON OF FLOOD FREQUENCY MODELS BASED ON EXTREME RAINFALL ANALYSIS

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Flood frequency analysis often copes with scarcity of hydrometrical data. The use of the whole available hydrological information, both floods and rainfalls recorded in a large homogeneous area around the examined basin, improves design flood estimation. Parametrical methods of identifying these areas have some attraction but could give bad results. Moving from the index flood method, a hierarchical regional approach, employed in the Italian VAPI flood evaluation project, gathers all the extreme hydrological series belonging to an homogeneous area, whose extension depends on the order of an appropriate statistics. Particularly TCEV distribution, employed in this procedure, performs daily rainfall analysis for the identification of homogeneous hydrometric regions and subregions. Moreover hourly rainfall analysis is performed for index flood relationships. The growth curves so obtained are robust enough but attention must pe paid essentially to the regional estimation of index flood. Another interesting approach exploits pluviometric information for flood distribution by assuming rainfall excess fully transformed in runoff volume. This procedure, performed by the French AGREGEE model, fits directly local flood data in lower return period domain. For higher return periods it derives the slope (gradex) of flood distribution from the distribution slope of extreme daily rainfall recorded in a representative site of the basin. The choose of this pluviometric site and the threshold of rainfall data computed for flood gradex estimation are some of the peculiar steps of the procedure. Both AGREGEE and TCEV models assume different behaviour of the flood's CDF for low and high return periods. A more detailed comparison arise from the application of the models on various European hydrological data base.

REGIONAL GEOSTATISTICAL ANALYSIS OF VERY EXTREME RAINFALL AND FLOODS

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Natural hydrometeorological disasters in the Mediterranean region are generated in the past essentially by outlying events characterized by extremely large rainfall intensity and rare occurrence. Because of their rare occurrence, these extreme events can be treated only on regional frequency bases, to reduce parameter uncertainties estimation in gauged sites, and for risk evaluation in ungauged sites. A statistical regional model includes (i) a probabilistic model, which can explain the extraordinarily high rainfall and floods observed in the past; (ii) a regionalization model, which can take into account the observed spatial variability of the statistical parameter of the probabilistic model. Here, a regionalization model is shown, based on TCEV distribution probabilisti model, with a geostatistical analysis of its parameters. The regional model considers that the observed variance comes from two sources: sampling variability, due to uncertainties into point estimates, and spatial variability, due to effective difference between sites. Usual geostatistical techniques refe to the exactitude property in gauged sites. At-site estimates are affected by sampling uncertainty, that can be predominant for high order parameters. An iterative procedure is implemented, which allows to obtain the spatial structure of the noiseless variate. First results are shown, with reference to a case study for an Italian region. The objective differentiation between areas with different risk is one of the most important finding of the proposed regionalization procedure.

ANALYSIS OF THE METEOROLOGICAL PATTERNS PRODUCING FLASH FLOOD IN THE IBERIAN PENINSULA

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During October and November 1997, more than twenty people died in the Iberian Peninsula as a result of flash flood. This situation repeats every year. The meteorological patterns that produced the intense rain that resulted in flash flood differ widely. Very intense synoptic patterns like front or cutt-off-lows, mesoescale convective systems or even intense storms can produce flash flood. In this study we analyze the meteorological patterns producing flash flood in the Iberian Peninsula in the last ten years.

SCALING OF REGIONAL FLOODS - AN L-MOMENTS APPROACH

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An approach to analyse scaling properties of floods from expected order statistics and L-moments is here developed further with respect to the procedures for determining scale coefficients. A scaling relation has been introduced for the expected order statistics, which allows the derivation of a scale dependence of L-moments, L-moments ratios and of parameters of theoretical distribution functions. The method used to estimate the scale coefficients has a significant influence on the behaviour of the tails of the scaling relation. The effect of this is illustrated on scale dependences for the GEV distribution, with the EV1 as a special case, applied to a Swiss data set consisting of 182 observation series with at least 20 years of instantaneous floods.

INCREASING FLOODING RISK CONSIDERING SEDIMENTATION IN THE RESERVOIR

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Reservoirs not only trap the incoming sediment load but also reservoir sedimentation increases the flooding risks because of aggravation upstream of the reservoir. Reservoir sedimentation results in loss of storage capacity for flood control and/or water supply. Sedimentation in reservoirs is a random variable and the value of sediment coming to the reservoir and/or passing the outlet, should be considered as a random variable. In the study a probability distribution function was found for the accumulated sediment in the a reservoir. Therefore the value of accumulated sediment for any year during the life time of reservoir was estimated. Accordingly with considering the initial reservoir capacity, the capacity of the reservoir was estimated for any year after the construction of the reservoir. Obviously the reservoir capacity is decreasing. Applying the Moran's Model for reservoir sizing considering the dependence of reservoir capacity with time, the probability of overflow for every year after construction of the reservoir was obtained. The results of the study shows how the risk of flooding in downstream of the reservoir is increases during the life time of a reservoir.

REGIONALIZATION OF THE EXTREME ANNUAL RAINFALL USING THE TWO-COMPONENT EXTREME VALUE MODEL : DISCUSSION AND APPLICATION

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This paper presents the regionalization method of maximum rainfall based on the cumulative distribution function (CDF) of the Two-Component Extreme Value (TCEV), developed by Rossi et al (1984) and its application on the daily maximum annual rainfall samples over the region of Minas Gerais (Brazil). This statistical model is based on the product of two exponentials, both representing a Poisson process: the first corresponding to the most frequently maximum rainfall generated and the other corresponding to the outliers . Theoretical aspects of the model are briefly presented and discussed. The regionalisation technique is divided in two parts.The first regionalisation level consists in defining the homogeneous regions.. Working with dimensionless values, the data of the homogeneous regions are pooled together to give a single series of station-year. The second regionalisation level consists in defining sub-regions where the third paremeters of the cumulative distribution function TCEV are constant. The procedure used is a first step to define hydrological homogeneous regions related to the flood frequency studies.

NH2 Meteorological and hydrological hazards (co-sponsored by HS)

04 Modelling and flood mapping in rural and urban areas

Convener: Oberlin, G.
Co-Convener: Roth, G.

Sponsorship: EC/DG XII/Natural Hazard Section, CEMAGREF

MODELLING THE MAXIMUM PROBABLE FLOOD IN A LARGE ROMANIAN RIVER

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In modelling the probable maximum flood (MPF) a deterministic method was used, based on the integration of the probable maximum precipitation (PMP) by means of the rainfall-runoff model.
The quantity, distribution on time and space are determined from the genetic procedures which are based on the maximisation of the some observed extraordinary rainfalls.
The rainfall-runoff model simulate the following components: the mean inflow, effective rainfall and the total flow on each sub-basin, the composition of the flood waves and their routing within the channel.
Finally, some aspects of the affected area are presented, as well as the change of the parameters of routing of flood.

USE OF WEATHER RADAR FOR THE MONITORING OF COMBINED SEWER OVERFLOWS IN BARCELONA AREA.

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In Mediterranean region, climatological factors make combined sewer overflows a major urban pollution problem that should be monitored and controlled. Some on line management solutions require the use of real-time models to forecast flows at the most sensitive points of the combined sewer systems. These models need high spatial and temporal resolution of the rainfall field that are not sufficiently reproduced by a conventional rain gauge network. Weather radar is introduced as a very useful tool for reproduce the spatial fields. This paper presents a case study where the use of rainfall estimates from radar images is compared against the use of a raingauge network in terms of the ability to predict sewer flows in an urban basin located in Barcelona. The results show that the use of radar data enables the combined sewer system model to improve the reproduction of observed flows, and they provide support for the idea that the spatial description of rainfall is a key problem in modelling events giving rise to combined sewer overflows.

MAPPING OF FLOOD PLAINS. THE CASE OF THE SESIA RIVER

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The Piemonte Region, within its institutional competencies regarding natural risk forecast and prevention, is experimenting a real-time flood forecasting system, aimed to civil protection. This system is made up by an operative structure that carries out forewarning operations, by an hydraulic-hydrologic model that allows flood forecasting and by a flood risk analysis that leads to emergency planning management.
This poster shows a method for flood risk assessment and its application to the Sesia River (left tributary of Po River). An analysis of main flood events involving Sesia River, occurred in the past fifty years (1954,1968,1977,1993,1994) has been performed in this view through air photography, historical sources, and field surveying studies. Moreover an hydraulic model that leads to flood forecasting has been used to define free boards in crossing and defence building, with reference to several different floods. Finally, all these studies allowed to recognise the most vulnerable areas close to the river, outlining both the main flood flow zone in a significant event (1993) and the lateral zone at its sides at flood risk in case of events characterised by flows comparable to those measured in November 1968.

FLOOD PLAIN ZONING ON HEADWATER

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Flood plain zoning is a well known non-structural measure and also a powerful tool in different aspects of the flood protection management. We should extract on flooded area: flood way, area flooded by ten years return period flood, area flooded by hundred year return period flood and area flooded by maximum probable flood. On headwater streams we suggest that river bank erosion and sediment deposition should be incorporated into the zoning. A few hours of inundation can not damage a structure as much as soil and river bank erosion can. Also sediment transport could completely change hydraulics conditions on flooded area. Potential erosion can be estimated by hydraulic and sediment transport models, geological data, and using experience with previous floods.
The most important characteristics of a flood for flood protection are the time lag from the beginning of rainfall to the peak discharge, the time duration of the flood wave, and the maximum velocity of the rise of water level.

THE EXPERIENCE OF THE LIGURIA REGION IN THE EXTREME EVENTS MANAGEMENT.

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In the past years many efforts have been spent in research for the realisation of reliable systems for flood prediction. The final purpose of this work is an enough early and efficient communication of the flood warning. Very often the research results in meteorological and hydrological prediction are cancelled by the weak link of the chain: the information transfer from the scientific community to ordinary people. In the past few years in Italy the Liguria Region attempted to produce an efficient system for flood prediction, exploiting the most recent results in atmospherical and rainfall runoff modelling, and able to transfer, in the most efficient way, the meteo-hydrological warnings to population living in regions characterised by a complex horography. Rainfall and meteorological fields produced by a high-resolution Limited Area model are analysed in order to define the basin classes for which the conditions are potentially hazardous. A discharge classification allows to link the water level in the river with a risk level and different actions to undertake. Once hazardous conditions has been noticed, warnings containing the risk level for each basin class are sent to local authorities. All these knowledges, described before, represent a real help to briefly transfer a clear message to the population, allowing a simple and efficient management of the flood risk.

THE NATURAL RISK SITUATION HALL

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The natural risk situation hall is an operative service, where all the environmental data measured by the regional network of ground stations (about automatic 160 stations, plus about 50 snow manual stations) and other non conventional data are collected (satellite and radar images, seismic network maps). All measurements are acquired in real time, with a maximum delay of 10 minutes. The measures related to the precipitation and river levels are directly comparable with the data observed during the past floods. A centralised informative system was initially set up to standardise the different messages and observed data and to manage them with homogeneous tools. Afterwards a monitoring system, operative for 24h /day, was implemented to follow the effects of heavy rain or snow precipitation hazardous events in the Piedmont Region. Some procedures turn the raw observed data into recommendations and messages for the authorised people devoted to alarm in case of extreme meteorological and hydrological events. The staff also perform statistical elaboration of the data, dissemination to a large set of users of scheduled and exceptional bulletins, regarding the meteorological situation and its forecast, snow and avalanches danger, hydrologic alarms, seismic activity on the region. The information delivery is carried out by fax, by telematic distribution (e-mail, internet, special connections); a telephone service is up to date every day. A very complex informative system supports the operative structure making available a data base that collects and archives all the data. Also display tools are studied on purpose to allow a friendly fruition of heterogeneous data.

THE EFFECTS OF FLOODPLAINS ON FLOODWAVES: AN ANALYSIS AND COMPARISON OF DIFFERENT MODELING TOOLS

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In the aftermath of the floods of 1993 and 1995 on the Nahe River in Germany, questions were raised on the effects of floodplains on downstream flooding. As a result, mathematical simulation tools of varying complexities were tested and utilized in order to develop a simple method to quickly estimate floodplain retention properties. A parametric technique that modeled the flows in the main channel and the floodplains separately through a diffusion wave approximation was first applied. Although this simplified method used only channel properties averaged over entire reaches and was known to over-estimate floodplain retention, it provided a good general estimate of the influences of the floodplains and could be applied quickly. It was found that for the Nahe River, the floodplains provide negligible retention for floods with the volumes associated with the 1993 and 1995 events. For events of smaller duration and magnitude, thus lesser volume, the retaining capacities of the floodplains are greater. A 1-dimensional unsteady flow (full dynamic wave) model was then applied. This yielded the same conclusions as the simplified parametric method, but also provided more accurate quantitative results. A simpler 1-dimensional model, which modeled the floodplains and the main channel separately through the Muskingum-Cunge routing method, yielded similar results to the unsteady flow model. At the highest degree of complexity, 2-dimensional dynamic wave modeling provided more understanding into the reasons behind the lack of floodplain retention in the Nahe River. It could be seen that once there was an appreciable volume of water in the floodplains, it began flowing, thus transforming the floodplains into a moving body of water. Often, this flow would short-cut river meanders. Thus, although the water in the floodplains flowed slower, it traveled a shorter distance, thus arriving downstream at approximately the same time as the floodwave in the main channel. The 2-dimensional model was also found to be advantageous in its ability to delineate the physical extent of flooding.

ESTIMATING EXTREME DISCHARGE VALUES OF SMALL WATER COURSES IN TRANSDANUBIA/HUNGARY

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On the basis of discharge data at 51 reliable gauging stations in the mountainous and hilly region of Transdanubia/Hungary (29,000 km^2), simple empirical formulae and graphical methods have been developed in order to estimate critical extreme discharges for ungauged stream sections in catchment areas between 30 and 3000 km^2.

For estimating the flood discharge $HQ_{3\%}$ of three per cent exceedance probability, three different methods have been used:

(a) Assuming the validity of Csermák's formula, $HQ_{3\%} = B_{3\%} \cdot A_E^{0,5}$, the isoline map of the flood discharge coefficient $B_{3\%}$ has been updated by using observation data of three decades.

(b) In the generalized form the exponent n is treated as a free variable: $HQ_{3\%} = C_{3\%} \cdot A_E^n$. For each of the seven subregions in Transdanubia, the optimum value of the parameters $C_{3\%}$ and n has been determined.

(c) Likewise in a grouping according to subregions a relationship between the quotient from flood discharge and mean discharge, and the catchment size A_E has been established.

On the basis of a comparison of the results obtained by using these three empirical methods, it is recommended to use Csermák's formula preferentially in the future as well, taking the revised isoline map of the coefficient $B_{3\%}$ into consideration.

In Hungarian water resources management the channel forming low discharge Q_m is interpreted as the discharge pertinent to the point of inflection of the flow duration curve. For its estimation an empirical relationship has been used yielding the quotient from Q_m and the mean discharge as a function of the catchment size A_E for the total area of Transdanubia.

CALIBRATION OF A RAINFALL-RUNOFF MODEL USED IN FLOOD FREQUENCY ESTIMATION

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The calibration of a conceptual rainfall-runoff model, the Probability Distributed Model (PDM), is described in the specific context of comparing flood frequencies estimated from simulated and measured flows. To reduce the dimensionality of the calibration problem, routing store parameters were first established by recession curve analysis. A Monte Carlo procedure was then used to search for parameter sets that best reproduced observed flow data, where goodness-of-fit was assessed via four objective functions, designed to give different degrees of weight to peaks in the flow time series. Examples are shown of the results of the numerical procedure, and of the benefit of manual parameter adjustment to improve the 'simulated' flood frequency distributions in some cases. Results confirm that the primary aim, to achieve good flood peak predictions, is best served by using an objective function strongly weighted towards peak flows. However, other aspects of the flow regime are also considered, as confidence in the modelling approach will be greatest when these are reproduced well. Finally, multivariate sensitivity analysis shows that there may be many possible acceptable sets of parameters, for any given measure of fit. Checks of flow duration curves may be useful in discriminating between these alternative calibrations.

MAPPING FLOOD PLAINS FOR A BETTER RIVER MANAGEMENT

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Within the Floodaware European project, we propose a new flood plain management method based on the comparison of hydraulic information with land use information. The use and crossing of distinct information layers (of hydraulic, topographical and geographical type) argue for the use of a G.I.S. (Geographical Information System). However, in order to avoid the addition of a G.I.S. which is a complex and heavy tool, dealing with a large amount of complex data, to other essential software such as the topographical and hydraulic numerical models, we consider that a global geomatics model, having all the needed functions (from the flood management point of view), including the typical ones of the G.I.S., should be developed. The G.I.S. concepts and functions we propose are well enough in agreement with the map-making process of the flood plain management, but the current G.I.S. implementations require the development of complex interfaces which have to take into account the topographical and hydraulic tools used in this field. A better solution is to identify and to define a single type of basic geometrical object from the set of geometrical, geographical and hydraulic constraints. In this way, a single topographical data base is built, on which all main functions of G.I.S. are developed. These functions are integrated into the different cartographic and hydraulic modules, used to simulate the river flows.

EFFECTS OF RAINFALL DATA QUALITY ON FLOOD FREQUENCIES IN SIMULATED STREAMFLOW

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Flood frequencies can be estimated by analysis of simulated flow data, generated using a conceptual rainfall-runoff model. This approach to flood estimation, which is now receiving increasing attention as an alternative to event-based methods, avoids the problem of specifying antecedent conditions for a design event. Also avoided is the need to specify individual design storm depths, durations, profiles and return periods. Instead, measured or synthetic rainfall time series are treated as a continuous input. The potential effects of rainfall data quality are therefore an important concern, which is addressed in this paper. Flood frequency estimates derived from simulated flows will be presented for three contrasting catchments in the UK (one upland/rural, one urbanised and one with a permeable geology). In each case, recorded hourly rainfall and flow data have been obtained for long periods to allow calibration of the PDM rainfall-runoff model, with strict quality control procedures being applied to the rainfall data. Flood estimates from the simulated and measured flows are compared using peaks-over-threshold analysis. A common problem that may affect the flood frequency estimates is the presence of gaps in autographic raingauge records, which can be addressed using an in-filling technique. In-filled gaps were inserted at increasing frequencies into the quality-controlled hourly rainfall data to investigate the effects of reductions in rainfall quality, and comparisons made across the three catchments.

Model and Spatial Database to Assess Design Peak Flow Rates in the Walloon Region (Belgium)

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Managing and planning rural catchments require the setting up of efficient hydrologic tools. To this end, the Unité d'Hydraulique Agricole of the Faculté Universitaire des Sciences Agronomiques de Gembloux has combined a Geographic Information System, covering the whole Walloon Region, with the hydrologic model SWRRB-WQ, adapted to the Belgian conditions.
Associating the model with the GIS provide us with geomorpho-hydrologic information, spatially distributed on the studied basins, as well as design flow rates and daily flow rates. Let us underline that soil moisture is one of the variables of the model SWRRB-WQ and that it has an influence on the runoff rate, through a digital parameter : CN (curve number). The latter comes from the method used by the American Soil Conservation Service (SCS). Using the geographic database together with the model allows us to carry out a regional analysis which is linked to the catchment planning.
Examples of simulation analyses show the effects of Karstic areas and the links between sub-bassins.

AN INTEGRATED SYSTEM FOR MONITORING AND EMERGENCY MANAGEMENT OF FLOODS

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The need of hydrological modelling supported by well-developed monitoring systems appears more and more essential in the light of flood events occurred over the world in the last decade. Simulation models can be considered as preventive tools for flood hazard and risk evaluation. Only their integration with real time monitoring system lets solve those "rapid" problems regarding the assessment of the general flood situation and identify areas at greatest risk and in need of immediate assistance.
In this paper an integrated real time flood forecasting system realised on an urbanised basin in southern Italy, frequently interested by extreme flood events, is described.
The system is developed in four main modules, respectively: of acquisition and analysis of the real time rain and water level information given by the telemetering gauges; of calibration of the parameters of the rainfall-runoff transformation model; of forecasting of future rainfall based on stochastic point model; of simulation (deterministic and stochastic) of flood levels at critical points of the basin.
Such modules are integrated within the system with the aim of guaranteeing a continuous procedure between hydrological information directly measured on the basin and that ones obtained through forecasting procedures.

CONVECTIVE RAINFALL MAPPING AND THEIR RELATIONSHIP WITH FLOODS IN CATALONIA (SPAIN)

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The main floods events produced in the West Mediterranean Area are related with high intensity rainfalls associated with convective systems. For this reason the identification between convective rainfall and high intensity rainfall is very usual, although it is not always correct. After considering the different points of view, the authors have proposed a new parameter, β^*, which allows classify the rainfall events between non-convectives, moderately convectives or highly convectives, in basis to the 5-minutes intensity. This parameter has been previously analysed using the long rainfall rate series 1928-1981 of Barcelona. However, the objective of this paper is to show the application of this parameter as an index of the spatial convective distribution in Catalonia. This mapping has been made using the 5-minutes rainfall data from the SAIH (Automatic System of Hydrological Information) of the Internal Basins of Catalonia for the 1996 year. This system allows to have information in real-time of 125 raingauges covering an area of 16000 km^2. The 1996 year was characterizated by the extraordinary number of pluviometric events and floods along all the year. These results have been compared with the mapping made using a climatic parameter β and 30 years of monthly data. Finally, a conection between the damage events in the last years, the distribution of this parameter and the rainfall intensities have been made in order to estimate the main flood prone areas and to identificate the events with flood risk.

INUNDATION MODEL FOR FLOODPLAIN ANALYSIS

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The paper describes the use of a two dimensional unsteady flow hydraulic model that implements the complete De Saint Venant equation for floodplain simulation.
Aim of the work is to investigates flood inundation due to overtopping or break of levees accounting for the presence, in the inundated plan, of banks (like streets and railways) and of a network of drainage channel.
Simulation of hypothetical and one real floodplain illustrates the potentiality of the model to account for the microtopography, changes in the roughness coefficient and presence of urbanized areas.
Such a model is usefull for planning and civil protections plans.

FLOOD MODEL VALIDATION USING SAR IMAGERY

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2-dimensional finite element hydraulic models of floodplain flow have previously only been validated and calibrated against point hydrometric data, whereas the distributed nature of the models is more compatible with validation against distributed data. Flood maps derived from satellite SAR imagery via a semi-automatic image processing scheme are used to calibrate floodplain friction coefficients of a 2-D hydraulic model of a 14km reach of the river Thames, UK. Issues such as assimilation of topographic information and the associated errors in model predictions are addressed, in order to direct future surveying and modelling strategies. As more validation data becomes available, validation and calibration against SAR derived flood maps will enhance the predictive capability of these flood flow models.

USING GIS AND AERIAL PHOTOGRAPHS TO DETERMINE THE WATER LEVELS DURING FLOOD

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To map water levels in case of large floods, it is proposed to manage by GIS the great number of information extracted from aerial photographs. Our method is developed in 3 points: 1) segmentation of the flood plain in sectors with acceptable mean water depth, based on geographical limits and size criteria. 2) determination of minimum and maximum depth for each sector, based on the emergence or not of natural objets (vegetation, dikes ...). 3) amelioration of the estimation of the water depths, using all observed hydraulic connections between sectors (cracked dikes, flows ...). This amelioration is done solving a constraint system linking the different water levels estimated in 2). Application concerns Herault River for the November 1994 flood, with aerial photographs taken 6 hours after the maximum of flood. Results give good determination about water levels, the lateral dynamic behaviour of flood (1,5 m of difference in levels between centre and edges of plain), and the impact of dikes. These results are obtained without introducing neither general hydraulic equation nor local head losses coefficient. The great number of fuzzy information, compensate for the low quality of each one.

URBAN DEVELOPMENT AND FLOOD HAZARD

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Flash floods are a typical feature of the southern Europe Mediterranean coastline: they designed the morphology of the terminal floodplains of the many small and medium size torrents dissecting the rugged orography of the Mediterranean slopes of the Pirineos, Alpes Maritimes and Appennines. The urban development of the floodplains, staring from the Roman Empire colonization, was definitely unaware of the flood processes: the braided rivers used to drain during the flood season the alluvial plains were trained to a unicursal bed all along the Mediterranean arch. A few examples are presented, from the Middle Age to the present, of the urban development leading to the present high frequency of disastrous events. The effect of the railway extension along the coastline during the past century is analyzed. The expansion of coastal cities in the present century on the northern arch and their explosive growth in last decades in the eastern part, in Turkey and Syria, created the conditions of making the flash flood hazard one of the most demanding all along the Mediterranean coastline.

Organic matter content in soil results from the balance among primary productivity and leaflitter production, leaflitter decomposition, and abduction by rainfall events. The loss of wooded areas because of unwise management or natural accidents can condition this balance. Fires are particularly effective in causing vegetation destruction and soil exposure; moreover fires have some marked effects on physico-chemical characteristics of soil, since destroying organic matter in surface layers they alter permeability, porosity, aggregate stability and then erodibility of hillslopes. Surface runoff is also increased. Burnt areas of a small Ligurian river basin were identified over a period of 15 years, from 1982 to 1996. Recovery rate of vegetation cover and restoration of the original organic content and then of biotic control over erodibility in burnt areas were evaluated at the local scale. Decomposition tests and collection of leaves by traps to measure leaflitter production were also performed. Experimental evidence suggests that non-linear interaction between forest fire processes and extreme rainfall processes in small semiarid Mediterranean watersheds could leave to irreversible local desertification conditions.

ESTIMATION OF FLOOD PRONE AREAS IN A RIVER PLAIN BASED ON CONVENTIONAL AND LASER-SCAN DEVELOPED DIGITAL ELEVATION MODELS (DEM)

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Flood risk maps provide an overview of the areas threatened by possible flooding. The delineation of these at-risk areas is often a controversial issue. It was thus desired, through the testing of different methods, to develop a reliable tool for estimating the extent of possible flooding. This analysis was performed on the Nahe River (Rheinland-Pfalz, Germany), which experienced large floods in 1993 and 1995. A digital elevation model (DEM) with a 20 m horizontal resolution was already available for Rheinland-Pfalz. In addition to this, a short reach of the Nahe, between the villages of Martinstein and Sobernheim, was surveyed using an airplane-mounted laser scanner. This yielded a DEM with a 2 m horizontal resolution. Based on these two data sets, the first attempt to simulate the flooded areas from the 1995 event involved the utilization of a 2-dimensional unsteady flow model. As would be expected, the enormous quantity of data in the DEMs caused these simulations to be extremely time consuming. To develop a less time-intensive method to delineate flood-prone areas, two different planes representing the water surface elevations of the Nahe at a specific flow were created through the GRASS geographic information system (GIS). One was based on a constant water depth in the main channel at the upstream and downstream ends of the modeling reach, thus resulting in a plane of constant slope. The other plane was based on the flood simulation results of a 1-dimensional unsteady flow model. This provided a profile of water surface elevations throughout the reach, which was transformed into a non-constant plane. The areas under these two planes were considered to be flooded. In comparison to the 2-dimensional modeling, this method of overlaying previously computed water surface elevation planes on a DEM involved considerably less time and was easier to apply. The results of this method were comparable to those from the 2-dimensional model.

DELFT FLOODING SYSTEM: TWO-DIMENSIONAL HYDRODYNAMIC FLOODING SIMULATION. A POWERFUL TOOL FOR LANDSCAPE PLANNING AND RISK EVALUATION

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The at Delft Hydraulics recently developed 2D-hydrodynamics prediction package Delft-FLS, is specially suited to simulate the dynamic behaviour of overland flow over initially dry land, the influence of existing or future infrastructure, as well as flooding and drying processes on every kind of geometry, including lowlands and mountain areas. A robust numerical scheme allows for the correct simulation of sub-critical and supercritical flow. Internal boundary conditions are included to simulate dam-break / dike-break events. It can be coupled to a one-dimensional model in order to give more details where needed, speed computations and facilitate the study of flood events on natural river basins, polders, channel-networked regions and urban areas. This package provides a reliable prediction of the hydrodynamics of flooding events extremely necessary when dealing with disaster management, evacuation plans and flooding damage assessment. These predictions can be also used during landscape, infrastructure and urban planning phases as well.

THE FLOODING PROBLEM OF SPERCHIOS RIVER BASIN (GREECE). A STUDY, USING THE NUMERICAL MODEL MIKE 11

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This work is an introduction to a procedure used for the numerical simulation of Sperchios river basin. In this procedure MIKE 11 model has been used, as the most reliable model in river modelling. The water management of Sperchios river basin requires a large number of measurements and prediction of future situations like flooding. This research contains collection and consideration of all available measurements and estimation of the water quantity of the river basin. In this paper a number of runs from Sperchios River hydrodynamics are presented and two different scenarios for better understanding and integrated management of flooding discharges are analysed. In the first scenario it was approved numerically that the existing channel is not able to receive the 50-year sequences discharges. The result is the flooding of the river basin. The simulation shows numerous points were construction has to be made, to safeguard the riverbanks. In the second scenario has been approved numerically that the current situation of Sperchios river network without any other construction, can solve the flooding problem of Sperchios.

NH2 Meteorological and hydrological hazards (co-sponsored by HS)

05 Shallow landslides and rainfall triggering

Convener: Sorriso-Valvo, M.
Co-Convener: Versace, P.

Sponsorship: CNR (Consiglio Nazionale delle Ricerche), Universita della Calabria

ROCKFALLS ON THE N1 HIGNWAY IN LA RÉUNION ISLAND (FRANCE) : HAZARD EVALUATION FROM RAINFALL

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The 12 km coastal N°1 highway in La Réunion (Indian Ocean) is frequently hit by rockfalls which cause many accidents. The road is located at the toe of a cliff, typically 150 m high, of alternating stratas of basalt and volcanic tuff. The blocky nature of the basalt and the erodability of the tuff result in numerous falls (about 100 a year), mostly triggered by rainstorms (annual precipitation : 1 to 2 m). More than four years of data (every two hours) are at our disposal : rainfall (three locations) and record of pieces of rocks found on the road by a dedicated team.
Different statistics about rockfall occurrence have been made : distribution according to the month, or the section of road, volume per event, etc. The correlation between rockfalls and precipitations is obvious when seen at a monthly scale, but is difficult to quantify at a daily scale. One could roughly say that only half of the falls are clearly related to rain events. Different thresholds of rainfall per day have been tested, combined with several time delays between a rain event and a rockfall. This kind of analysis can be used for a traffic regulation : the road can be partially closed to traffic when some precipitation criteria have been exceeded.

THE EFFECT OF LAND ABANDONMENT ON SOIL WATER REDISTRIBUTION AND PREFERENTIAL FLOWPATHS ON SHALLOW LANDSLIDE INITIATION.

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The occurrence of shallow landslides is a common process in the basin of the Ríu Serpis (SE Spain). Because of the extent of the affected area, shallow landslides are the dominant form of hillslope erosion in this marly area and threaten the productivity of the bench-terraced agricultural lands and semi-natural slopes. The biological activity caused by the revegetation following abandonment results in an improved storage capacity of the topsoil. At the same time, the presence of macropores -preferential flow paths of water, possibly connected to shallow slide planes- shortens the response time of the soil mass to reach critical pore pressure conditions. Therefore, under given rainfall conditions, a larger area will be prone to landsliding after abandonment. This hypothesis that abandonment increases potential landslide activity, was investigated by rainfall simulations at locations with different land use conditions. Broad scale rainfall simulations with automated soil water dynamics monitoring (TDR) and tracer applications, and additional small scale experiments, were carried out on several terraces which were under culture or were abandoned for different periods. Infiltration patterns in the soil were measured, to study the heterogeneity in infiltration under plants and to study preferential flowpaths of water, which might be connected to shallow slide planes. Differences in general infiltration velocities were found under various types of vegetation, related to land-use history. On all plots with semi-natural vegetation, deep penetrating preferential flow along continuous macropore systems was observed and the heterogeneity of infiltration patterns and preferential flow paths were found to be more important on terraces which were longer abandoned.

HAZARD ASSESSMENT FOR RAINFALL-TRIGGERED LANDSLIDES

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Hazard and risk assessment for landslides may be carried out in a number of ways. The selected procedure may include formal analytical approaches, deterministic or probabilistic. However, less formal approaches, often used in practice, include considerable reliance on experience and engineering judgment. This paper is concerned with aspects of assessment based on observational procedures and data. Attention is devoted to the main hazard and risk requirements for the development of such procedures.

Historical records of landslide activation and reactivation may be available in some areas along with rainfall records. From such information and data the past frequency of landsliding can be assessed and conclusions can be drawn about the expected probability of landsliding in a temporal sense. However, such information is often limited and subject to significant uncertainties.

A modern approach based on observations at instrumented sites can be more useful and reliable in estimating the hazard of rainfall-triggered landsliding. Data from inclinometers and piezometers can be related to rainfall data. Periods of Peak subsurface shear movement as well as accelerating shear movement can be identified. Recently an innovative approach has been developed to study the relationship between antecedent rainfall and significant episodes or periods of shear movement. The most significant antecedent rainfall period for a particular area or region can be assessed from such studies. The method has proved very useful for shallow landslides which are often self-stabilising in character. The method also has potential for study of rainfall-triggered debris flows.

NH2

ANALYSIS OF TOPOGRAPHIC CONTROL ON SHALLOW LANDSLIDING USING A QUASI-DYNAMIC WETNESS

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A model for the analysis of topographic influence on shallow landslide initiation is developed and applied to a mountain experimental basin where high-resolution digital elevation data are available: the Cordon catchment (5 km^2), in north-eastern Italy. The model builds upon a theory for coupled shallow subsurface flow and landsliding of the soil mantle previously proposed by Montgomery and Dietrich (1994). The model uses a 'quasi-dynamic' wetness index to predict the spatial distribution of soil saturation in response to a rainfall of specified duration. The rainfall predicted to cause instability in each topographic element is characterised by duration and frequency of occurrence. This provides a practical way to identify the relative potential for shallow landsliding. Furthermore, this approach provides a theoretical link between methods based on intensity-duration thresholds and explicit, physically-based models of slope instability. An inventory of landslide scars is used to document sites of instability and to provide a test of model performance by comparing observed landslide locations with model predictions. It is found that the model reasonably reproduces the observed distribution of landslide locations, although spatial variability of soil properties and hydrologic complexities not accounted for by the model complicate prediction of where landslides occur within areas of similar topographic control.

EVENT-INDUCED CHANGES TO LANDSLIDE TRIGGERING THRESHOLDS

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Rainstorm-triggered landslide events alter terrain conditions sufficiently to affect susceptibility to future landsliding. In one hill country catchment changes to inherent resistance (measured by the factor-of-safety) resulting from a major event indicate , in future, small triggering rainstorms would be more affective in producing landslides while moderate to large storms would be less affective. The mechanisms responsible for changes in inherent resistance include mass movement induced redistribution of regolith, changes to regolith properties, changes in regolith depth and the development of unsupported erosional scarps. The influence of these mechanisms on susceptibility of typical slopes has been investigated and quantified by the use of a combined hydrological slope stability computer simulation model. The net effect is expressed in terms of time to failure and total rainfall required to trigger movement.

REGOLITH EVOLUTION AND THE CONTROL OF SHALLOW TRANSLATIONAL HILLSLOPE FAILURE : USE OF A 2-DIMENSIONAL COUPLED SOIL HYDROLOGY-SLOPE STABILITY MODEL

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Recent advances in physically-based modelling now enable highly detailed investigation of hydrological conditions at the time of failure, particularly for shallow translational failure. Modelling is a non-invasive technique and provided adequate parameterisation and validation data are available it is possible to apply the 2-dimensional coupled soil hydrology-slope stability model to a variety of research problems. Available models produce high resolution information in both time and space, enabling detailed rainstorm data to be included for soil profiles which are highly differentiated in terms of geotechnical and hydrological behaviour. One of the main advances has been in investigating the ways in which temporal evolution of regolith over Holocene timescales has altered the probability of shallow translational failure. In New Zealand slopes have been stable during much of the early part of the Holocene. Recent anthropogenic activity, mainly involving deforestation, has resulted in a phase of progressive regolith stripping. Following initial failures in which about 25 percent of the regolith is stripped from the slope, it has been suggested that the removal of the remainder is somewhat more difficult as thresholds for instability rise. However, extreme rainstorms are still capable of initiating slope failure. A phase of reduced stability then occurs as regolith is redeposited at the slope base, having modified hydrological and geotechnical behaviour. Application of physically-based models to this sequence of regolith stripping and evolution has broadly supported these conclusions. Importantly, model results have also permitted identification of appropriate climatic thresholds for slope failure for these different phases, and have shown how the hydrological controls on slope instability have altered over time.

NUMERICAL SIMULATION OF FLOW LANDSLIDES

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NH2: Meteorological and hydrological hazards
05 Shallow landslides and rainfall triggering

Flow landslides which get formed as a result of intensive precipitation constitute slope deformations in the form of viscous-plastic ground flow. For the numerical simulation of flow landslides movement a hydraulic model was used which before had been successfully used to describe snow avalanches and mud flows. In the mathematical model of the flow landslides use was made of specified relations which describe friction of soils and portray the peculiarities of the landslides movement. The numerical simulation of the flow landslides movement allows one to calculate the speed and the speed vector direction of the landslides at any point of the slope and to obtain the configuration of the landslides tongue in the plan and at arbitrary moment of time.

RAINFALL-TRIGGERED DEBRIS AVALANCHES IN THE MOUNTAINS OF BRITISH COLUMBIA, CANADA

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Debris avalanches, or open-slope debris flows, are extremely rapid catastrophic landslides which are triggered by heavy rains. Long triangular scars are commonly observed on aerial photographs of British Columbia forested steeplands on both logged and unlogged slopes. Since 1956 numerous debris avalanches have been documented on steep mountain slopes in British Columbia wher they have caused a number of deaths as well as substantial damage to property and the forestry resource. Debris avalanches can occur on slopes where there is no evidence of previous instability. Landslide volumes are generally the range 20,000 - 60,000 cu. m. Debris avalanche paths may exceed 500 m in length but involve only a very thin veneer (less than 2 m) of surficial materials. Based on eye witness accounts, the velocity of debris avalanches commonly exceed 10 m/s. A dynamic analysis of the 1990 Belgo Creek debris avalanche (estimated volume 23,000 cu. m) event indicated local velocities of as much as 20 m/s. Undrained loading may be an important mechanism in the development of debris avalanches and contribute to their high velocity. The behavior and occurrence of debris avalanches is to be contrasted with channelised debris flows which are generally recurrent in a given watershed and in which the velocity rarely exceeds 7 - 8 m/s.

MODELLING AND TRIGGER MECHANISMS OF SOIL SLIPS

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The available studies concerning soil slips triggered by critical rainfalls, in addition to a complex picture of knowledges, they point out that these surficial slope failures frequently determine unacceptable risk thresholds. As regards the spatial forecast, whereas it is clear the role of some predisposing factors (slope angles, cover thickness, etc.), to others (local variation of the pluviometric input, geotechnical parameters, etc.) the knowledge picture is less clear. Relatively to temporal forecast, are sufficiently consolidated some indications relative to the characteristics of the rain able to trigger shallow failures in the slopes; less clear are, on the contrary, the relationships between local and mean characteristics of the rainfall events. Therefore, as regards the mechanisms that govern soil slips initiation, the pluviometric conditions can play a double role: factor of trigger, factor that predispose the location. It follows the importance of the models that simulate the infiltration process of the rains into the shallow layers of soil, and the suitability to verify their potentialities. This type of investigation is carried out referring to some simple geotechnical schemes, inferred from the literature, and to some of the utilizable calculus codes. In particular, referring to the same pluviometric input and to the same physical parameters of the soil, it is shown the influence of the calculus codes in the evaluation of the pore pressures distribution in the upper layers of soil. Then, referring to a specific calculus code, it is shown the variation of the pore pressures distribution in relationship to rainfall conditions and physical parameters of the soils. Finally, the results altogether achieved allow to outline a possible methodological approach for the study of the soil slips, and they point out some searches necessary to typify contexts geo-environmental homogeneous with respect to the considered instabilities.

MODELS OF ANTECEDENT RAINFALL AND SOIL WATER STATUS APPLIED TO DIFFERENT REGIONS IN NEW ZEALAND

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Shallow rainfall-triggered landslides constitute a threat to population and environ-ment, as well as to infrastructure and industry in New Zealand. Models were deve-loped in the 1980'S relating landslide occurrence to rainfall. These models range in complexity from a simple analysis of daily rainfall to a comprehensive consider-ation of antecedent soil water status using a water balance approach. The latter approach uses as input daily climatic parameters (rainfall, temperature, evapotrans-piration) and soil characteristics (depth, porosity, texture, soil moisture capacity). In this study, the antecedent soil water status model is further refined by incorporating data on regional soil characteristics and drainage conditions. The model has been applied to three New Zealand regions using rainfall timeseries dataover periods ranging from 52 to 63 years. The analysis differentiates between non-triggering and landslide-triggering precipitation conditions. Probabilities of landslide initiation are associated with given rainfall magnitudes within each region. Spatial differences were identified, indicating variation in the landslide triggering response to comparable rainfall magnitudes. Factors influencing these differences include geology, climate, topography, and land use. Also of importance is the nature and reliability of recording procedures and landslide precedence. Calculated regional rainfall thresholds for landslide occurrence have the capability to be used as predictive indicators within landslide warning systems.

FEEDBACK EFFECTS OF RAINFALL-TRIGGERED SHALLOW LANDSLIDING

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Rainfall triggered landsliding is a common and widespread phenomenon in New Zealand, following extensive deforestation within the last century. Spatial variation in the relationship between rainfall and erosional response is recognised for a number of regions. However, the rainfall/erosional response relationship established for a given region shows a tendency for temporal variation. This variation can be attributed to mechanisms described as "ambient filters" and "event resistance", which operate as a result of successive landsliding episodes.
This temporal variation in susceptibility to landsliding has been investigated by comparing the stability conditions of a catchment on two historical occasions 23 years apart. Changes in relative susceptibility are interpreted as an alteration in the relationship between rainfall input and landslide response. A refined process model for landslide occurrence is presented, incorporating feedback loops resulting from the occurrence of the landsliding process. Results are also used for an initial calibration of a proposed model of landform relaxation. This model describes the development of and changes in catchment susceptibility to landsliding following significant environmental change and progressive erosion of the catchment.

A CELLULAR AUTOMATA MODEL OF THROUGH FLOW IN A POROUS SOIL FOR SHALLOW LANDSLIDE FORECASTING

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Parallel computing models represent a valid alternative to standard methods with differential equations in modelling complex phenomena. Cellular Automata (CA), a paradigm of parallel computing, permits such an alternative approach for modelling and simulating complex systems, whose evolution can be described in terms of local interactions of their constituent parts. When the basic laws of continuum mechanics cannot be directly applied without adding phenomenological assumptions, and the equation systems are not amenable to analytical solution, direct discrete modelling may represent a convenient alternative to the use of continuum models, followed by numerical discretisation. Water infiltration on a soil can be viewed as a phenomenon based on local interactions; the equation governing the flow cannot be easily solved without making substantial simplifications. Particular complexity arises for the soil composition and irregular ground topography. In this paper we describe a macroscopic CA model for simulating the water infiltration in a 2-layer slope model. The model assumes the upper layer of the soil as initially non-saturated and inhomogeneous, while the lower layer is impermeable. It describes the water infiltration and groundwater retention. Transformation of water storage into neutral pressure requires an ancillary computation code. Applications are performed on an ideal slope using different rainfall intensity and duration.

HYDROLOGIC THRESHOLDS FOR SHALLOW LANDSLIDES IN MOUNTAIN WATERSHED: A SPATIALLY DISTRIBUTED SIMULATION ANALYSIS

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The spatially distributed approach provides an insight of hydrologic factors of shallow landslides triggered by extreme rainfall events. For the purpose, we developed a fine resolution grid model of basin surface including a detailed soil characterization. The soil model includes the infinite slope stability equation, hortonian infiltration, weight of vegetation cover and root strength. The model provides the safety factor for each element at any time step as the representative index for slope instability as produced by a given rainfall hyetograph. We used this model to investigate slope dynamics for a small mountainous catchment in the Versilia watershed, NW Tuscany, Italy. Fine resolution soil and storm data allow to investigate the effects of temporal and spatial scales in the mathematical representation of complex physics. It is seen that one can reproduce the observed slope dynamics only if a high spatial distribution is adopted. Accordingly, the spatial distribution of estimated safety factor is capable of reproducing that of the mass movements occurred during the flood event. Further simulations using syntetic hyetographs can help evaluating hydrologic thresholds for shallow landslides in the catchment. Preliminary analysis of simulations indicates that the extention and spatial distribution of critical values of the slope instability index depend on the return period of total rainfall depth in a storm. This could perspectively allow to evaluate hydrologic thresholds for shallow landslides based on climate, soil and topography characterization.

LANDSLIDES TRIGGERED BY THE HEAVY RAINFALL ON JULY 1997 IN THE CZECH REPUBLIC

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On 4 - 9 July 1997 a heavy rainfall event heavily affected the eastern part of the Czech Republic. During 5 days the precipitation exceeded about 400 - 500% the long-term normal, with maximum 617 mm/5 days. Large areas were affected by slope instability. A several hundreds landslides were registered during this event. The roads, buildings and main railways were damaged in many places. Landslides were concentrated particularly in the region of the Carphatian Flysh, especially in the territory where a claystone formations predominate. Most of landslides had a short and dangerous evolution. In many cases the old landslide bodies were reactivated. The earthflows and stream-like landslides predominated. In the contribution the first results of landslide inventory and analyses are demonstrated.

RETURN PERIOD ASSOCIATED TO RAINFALL THRESHOLD FOR LANDSLIDE TRIGGERING

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The analysis of landslides triggered by rainfalls is based on the hypothesis that the behaviour of the hillslope can be assumed as stationary. In such case, it is possible to define some rainfall threshold for the triggering of the slide movement. Usually the threshold is defined on a filtered process, called mobility function, defined as a convolution between the rainfall intensity in the past and a filter function, characteristic of the landslide studied. In the paper an analysis of different landslides characterised by single or multiple movements in the Southern Italy is carried out. Particularly the difference among the various filter functions is studied, higlighting the different behaviour of landslides characterised by a rapid or a slow reaction to the rainfall input. Moreover the attention is focused on the variation of the return period associated at the rainfall thresholds. These latter are evaluated, for different durations, by assessing the minimum constant rainfall able to produce the attainment of the mobility function threshold. In such way, the dependence of the critical rainfalls on the duration is investigated. The return periods of these critical rainfalls are evaluated by a statistical analysis of the extreme rainfalls. The statistical distributions employed for the assessment of the return periods, are different according to the duration considered. For short duration (some days) distributions highly skewed are assumed, while for the rainfall accumulated on long period (of some week) distributions less skewed are preferred.

The Effect of Rainfall on Landslide Triggering in Northern Israel: an Example of Slope Instability in an Active Seismic Environment.

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Abundant seasonal rainfall combined with steep unstable slopes and a high level of current seismic activity contribute to increase the vulnerability of populations and of infrastructures in northern Israel as well as in neighboring areas. Understanding the effects of rainfall on the present non-seismic activity of unstable slopes is the key to further predictions of their potential co-seismic behavior. A multi-parameter monitoring project was undertaken over a period of 24 months on a dip-slope landslide. The present aseismic slip rate and deformation were quantified using five parameters: rainfall, water table level fluctuation, radon emission, surface and subsurface displacement. Results show that intense and irregular rainfall followed by a rapid recharge of the water table have little influence on the activity of the landslide whose slip surface is permanently located below the water table. This explains why past seismic-triggering of landslides also occurred during the dry season.

HSA5 Open session on hydrology and surface hydrological processes

Convener: Kiely, G.
Co-Convener: Bormann, H.

SMART2 MODEL APPLICATION TO TWO FORESTED CATCHMENTS IN FINLAND: EFFECTS OF EMISSION REDUCTION SCENARIOS

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SMART2, a revised version of the dynamic soil acidification model SMART, was tested at two forested catchments in Finland. The catchments belong to the network of Integrated Monitoring Programme. A forest growth routine and a more detailed description of nitrogen processes in soil have been included in SMART2. The aim of the study was to calibrate the model to two different datasets derived from the catchments with different characteristics and to compare the model behavior and applicability in them. An other objective was to predict the long-term effect of atmospheric deposition, originated from athropogenic sources, on soil and runoff water, giving different sce- narios of future deposition of sulphur and nitrogen. The emphasis was put on studying the acidifying effects of the deposition on soil and runoff water. Also the relation between nitrogen mineralisation and forest growth, and nitrogen leaching to surface waters were studied. The volume of the forest had a great impact on nitrogen prosesses. The scenario runs showed a decline in soil base saturation and surface water pH in response to the rapid increase of acidifying deposition due to increased emissions starting in 1960's. With the studied reduction strategies, environment deterioration can be stopped and the recovery will begin. The timing of the response depends on the stringency of the chosen abatement strategy.

RESPONSE TO EXTREME HYDROLOGICAL SITUATIONS IN THE STORAGE OF AN ANTHROPOGENICALLY AFFECTED SALT LAKE

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The Fuente de Piedra lake is one of the largest in Spain (13 km^2 of flooded area but usually less than 2 m of water height) and is located in an area -central Andalusia- with mediterranean semiarid climate. Its hydrological regime tipically follows a seasonal inondation/dessication sequence. This playa lake has been used for commercial salt production until the middle of this century. A number of structures -canals, pools, dikes, etc.- were built to favour such activity, most of which have disappeared in recent times by erosion/sedimentation processes. The lake is now a Nature Reserve of international ornithological interest. The 1989-1994 period included an anomalously wet year (1989-90) followed by four years of drought. Thus, in 1990 relatively high water levels were maintained and summer dessication did not take place; from 1991 to 1994 water stored during inondation season was very scarce. Modeling of the hydrological regime of the lake shows that: a) a perimeter canal may avoid that a significant amount of the runoff reaches the lake during rainy events; b) other previously designed structures can contribute to isolate different water bodies in low-level situations, affecting the storage determinations; c) groundwater flow to the lake occurs mainly during the summer seasons, and d) this flow can be locally reversed after the first intense recharge events which usually happen at the begining of autumn.

MODELLING FOREST TRANSPIRATION FROM DIFFERENT PERSPECTIVES

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For long, forest transpiration has been studied in many scientific disciplines such as plant physiology, hydrology, ecology, meteorology, soil science, etc. These disciplines apply their own methodology and studies forest transpiration at its own typical level of detail. This has resulted in many model concepts with different perspectives and varying complexities. In this study similarities and discrepancies will be discussed. The following three models are parameterised on a one year data set of a Douglas fir stand in the Netherlands: (i) SBL-Stewart (meteorological), where stomatal conductance is described by environmental response functions, parameterised on eddy correlation. (ii) Standflux (plant physiological), based on assimilation/transpiration relationship at the stomata level and scaled up to the full canopy parameterised on branch chamber measurements of leaf assimilation. (iii) Swif (soil water), where potential transpiration is reduced by a function of root density and soil pressure, parameterised on soil water content dynamics.

Regionalization concepts for hydrological modelling on different scales using a physically based model: results and evaluation

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Increasing the scale of hydrological models often induces a change of the chosen model concept due to required data and computer time. A regionalization scheme is presented which enables us to simulate regional water balances using a physically based model without loosing the spatial distribution of model parameters and simulation results. This method bases on a combination of deterministic and stochastic approaches and can be applied in any catchment without calibration. A region is an ensemble of numerous hydro-pedotopes. The aim of the concept is to calculate the water balance of a catchment of interest using a limited number of representative instead of all hydro-pedotopes which were derived by overlaying information concerning soil, relief and land use. In order to reduce the number of simulation units areas with similar hydrological behaviour should be grouped. Due to non linearities they cannot be clustered using parameters or parameter combinations. Therefore, simplified soil profiles are used to define representative hydro-pedotopes. The complex soil profiles observed in a given catchment are linked to the simplified by means of integral measures called regionalization indices. Applying this scheme the required computer time can be reduced up to 95% which is shown by presenting simulation results of the upper Leine catchment (1000 km^2) in northern Germany. Due to this approach for each time and place in a catchment a description of the hydrological processes and fluxes is possible.

REPRESENTATION OF NATURAL HETEROGENEITY IN RAINFALL-RUNOFF MODELS.

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In the past three decades increasingly complex rainfall-runoff models have been developed to give a detailed representation of the relevant hydrological processes that occur during storm events. Since heterogeneity present in natural systems is enormous, there are virtually no limits to the amount of information which can be used in a rainfall-runoff model to describe characteristics of the modelled system. However, due to measurement- and modelling errors it does not hold that input of more information on system characteristics will automatically lead to better model output. Therefore it is important to gain knowledge on natural heterogeneity and its representation in rainfall-runoff models to obtain the best possible output results. Research at Delft University aims to give some guidelines on this subject. For a number of catchments, a procedure is developed to vary the amount of spatial information of a number of parameters and variables in a rainfall-runoff model and the effect on the output (calculated runoff at catchment scale) is tested. Results are implemented with the aid of statistics of the characteristics of the catchments under study. In this way, a relation is established between the present heterogeneity of catchment characteristics and the way this heterogeneity should be modelled.

MODELLING BY USING TOPOGRAPHIC INFORMATION. APPLICATION OF TOPMODEL TO A MEDITERRANEAN BASIN.

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The conditions of the Mediterranean region, with long dry periods and heavy rainfall intensities, request the development and adaptation of particular rainfall-runoff models. In this sense this work focuses on the possible usefulness and relevance of the basin topography on predicting flood peaks. For that, an application using TOPMODEL model to a representative basin, the Ample, in Southern France, has been carried out. The study case is an event by event analysis (9 events), where Monte Carlo simulations are used to calibrate the model and results are analysed using the GLUE likelihood measure methodology. Thanks to the GLUE approach the resulting parameter values and flow responses allow a discussion about the existence of unique optimum parameters as well as show a marked seasonal variation of their value and distribution. Furthermore from the obtained results some suggestions to improve the model can be presented.

EVALUATION OF A CATCHMENT-BASED LAND SURFACE MODEL FOR GCMS

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A new GCM-scale land surface scheme that explicitly models subgrid soil moisture variability and its effects on evaporation and runoff has recently been developed. In a break from traditional modeling strategies, the continental surface in the GCM is separated into a mosaic of hydrological catchments, with boundaries that are not dictated by the atmospheric model's grid but by topography. The energy and water balance equations are solved at every timestep in each catchment. Following existing catchment hydrological models, topographic indexes are used to define the spatial distribution of the catchment moisture. This allows the catchment's separation into different moisture regimes that contribute differently to runoff, baseflow and evaporation. Topographic data are used to derive the parameters of a preprocessed distribution function of the catchment moisture. The model also includes a root zone moisture variable to allow for soil wetting fronts following storms, and to avoid the limitations of catchment models in regions of little to moderate orography.
This talk describes the evaluation of the model is evaluated over North-America through the comparison of simulated and observational runoff data.

COMPARISON OF FOREST EVAPOTRANSPIRATION FROM ECEB MEASUREMENTS OVER A FOREST SPRUCE STAND WITH THE WATER BUDGET OF A CATCHMENT

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Evapotranspiration exceeds in most cases loss through discharge in the water budget of Central European forests. Its direct determination is of great importance to understand the process of water exchange between forest and atmosphere.
Evapotranspiration of a 28 m tall, 110 years old spruce forest at the Anchor station „Tharandter Wald" is measured by eddy covariance energy balance method (ECEB) in 42 meters on a micromet tower. The analysis is based on measurements of sensible heat, radiation components, stored heat in soil, biomass and air in the stand space. In dry periods evapotranspiration can be estimated from evapotranspiration induced variation in the water gauge of a small river („Wernersbach"). The forested watershed „Wernersbach" has an area of 4.6 km² and is situated in the forest „Tharandter Wald" in the lower part of the Eastern Ore Mountains.
For the hydrological years 96/97 and 97/98 comparison of the difference between precipitation and discharge of the watershed „Wernersbach" with measured ECEB evapotranspiration at Anchor station, 5.6 km away from the catchment, showed good agreement. These results allow a positive view of the possibility for the regionalisation of evapotranspiration.

TEMPORAL VARIABILITY OF EFFECTIVE VALUES OF SOIL HYDRAULIC PROPERTIES AT THE FIELD SCALE

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Temporal variations in the effective values of soil hydraulic parameters were evaluated under different soil management, crop type and growth stage. The parameters describe the hydraulic behaviour of the soil in terms of infiltration and surface runoff for a 15 x 100 m² experimental plot. The effective value of the saturated hydraulic conductivity was estimated by computing the ratio between infiltrated discharge and the area of the plot when a constant discharge was delivered to the plot over a period which was long enough so as to achieve a steady outflow. Manning's roughness coefficient and other parameters were estimated by minimising the square of the errors between the outflow discharges measured during the experiments and the those computed by a mathematical model simulating runoff and infiltration (Green and Ampt equation) in a coupled way. The value of the saturated hydraulic conductivity varied in time over more or less one order of magnitude depending on soil management. The value of the roughness coefficient was strongly related to crop growth stage and varied seasonally by about 40%. The results confirmed that the calibration and validation of hydrologic models should be carried out over a range of soil and crop conditions.

HYDROCARBONS AND GEOCHEMICAL PROCESSES IN THE BOTTOM ENVIRONMENTS OF RUSSIAN SEAS COASTAL ZONES.

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VNIGRI multipurposed geochemical investigations in the shallow shelf of Baltic, Caspian, Okchotsk and Pechora seas include the study of geochemical and bio-geochemical processes in aquatic systems under the influence of hydrocarbons emanations from the lithosphere and oil-pollutions. The methodical complex of mapping and genetical identification of subaqueous geochemical fields are based on the detail study of gases composition, waters, bottom sediments, indicator groups of microorganism distribution.
Lithodynamic and physico-chemical conditions and the limits of lithofacies differ-entiation of geochemical fields forming were determined in the bottom environ-ments of shelf, coastal and continental zones.
In natural conditions in Pechora sea coast the composition and the regime of gas flows on the lithosphere-hydrosphere interface were studied. The increasing of hydrocarbons and gases flows above oil accumulated zone in deltha Pechora river was fixed.
Above oil-gas accumulated zones, oil-gas sites, pollution sites the anomal proc-esses of interaction epigenetic hydrocarbons and biomineral complex of bottom environments were fixed and studied.

GENETIC ALGORITHMS, NEURAL NETWORKS : IS IT POSSIBLE TO USE THESE « MODERN CONCEPTS » FOR HYDROLOGIC MODELS ?

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The definition and optimisation of parameters is a major problem in modelling. Lately algorithms deduced from biological concepts using neural networks or the laws of genetics are gaining popularity. We have been able to develop a watershed model that applies these principles. This model, which we call CORIANDRE, has the structure of a classical multi-reservoir model. In its basic version we define three reservoirs that are interconnected. They are conceived like traditional linear reservoirs except that the outflow coefficients are not constant. Their values can evolve with time as a function of the quantity of humidity stored in the system. Since the shape of these outflow functions is initially unknown we use a type of analytical functions usually related to neural networks design. These functions allow to model a large variety of curve-shapes with very few parameters (we used four parameters for each outflow function). All parameters are determined by a genetic algorithm. This algorithm, based on Darwin's law, proceeds in different stages. Through the processes of duplication, crossing and mutation a optimum set of genes, or in this case, parameters is determined. We have applied this model to several data sets coming from rivers in France. The shapes of obtained outflows functions are consistent with what is expected from a physical point of view and the overall modelling results are very encouraging.

CORIANDRE, TOPMODEL, DPFT : COMPARISON OF TREE WATERSHED MODEL CONCEPTS IN RESEARCH OF AN APPROPRIATE REAL TIME FLOOD FORECASTING TOOL.

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Flood forecasting is a major concern for hydrologists. When a model has to be selected one is confronted with a wide variety of modeling concepts. We have examined three different models to see whether the current flood forecasting policy at Electricité de France (EDF) can be improved. The DPFT method, currently applied at EDF, is based on the unit hydrograph theory. Using an inversion algorithm the model allows, to identify by successive convolution and deconvolution, the unit hydrograph and corresponding net rainfall. A second step consists to calibrate an analytical production function to reproduce this net rainfall. TOPMODEL is a well known model based on the theory of expanding and contraction contributing areas whose extent is determined through the topography of the watershed.
The last model, CORIANDRE is a model that has recently been developed at EDF. In principle it is a multi-reservoir model which has been improved by using new modelling techniques borrowed from neural networks design and Darwin's evolution theory (genetic algorithms). We applied the three models on data from several catchments and compared the results. It appeared that for average floods all three models performed equally good. When it came to events with a large contribution from groundwater CORIANDRE gave better results. From an overall point of view this model displayed a higher flexibility in particular situations.

Influence of rooting depth on the simulated hydrological cycle of a GCM

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The hydrological cycle is one of the key issues in simulating the climate with an atmospheric general circulation model (GCM). This study will show that rooting depth and thus the field capacity (maximum soil water-holding capacity of the root zone) have a major influence on the simulated hydrological cycle of a GCM. We consider three different climate simulations of the GCM ECHAM4-T42: a) a control experiment using a dataset with spatially distributed field capacities, b) a simulation using optimized rooting depths in the tropics which are generally deeper than in the control experiment, c) a sensitivity simulation using a constant rooting depth of 60 cm in the tropics which is shallower than the corresponding average rooting depth of the control experiment. We evaluate the simulated hydrological cycles using the *Hydrological Discharge* model which simulates the lateral waterflows on a 0.5° grid using input fields from the GCM simulations. Its model parameters depend on spatially distributed land surface characteristics. We compare the simulated discharges of a few large catchments to observed discharges as well as the simulated precipitation for these catchments to different climatologies. For a specific catchment, differences in the hydrological cycle between the climate simulations may be directly based on differences in rooting depth due to a different evapotranspiration, or may be related to changes in the circulation patterns, even in catchments where the rooting depths are the same in all three simulations. The effects of rooting depth changes are discussed and conclusions for a future improvement of the representation of the hydrological cycle in atmospheric GCMs are drawn.

INFLUENCE OF ROOTING DEPTH ON THE SIMULATED CLIMATE OF A GCM

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Rooting depth determines how much water can be stored in the soil which is accessible to the vegetation for transpiration. In order to investigate its influence on climate, we conduct two simulations with an atmospheric General Circulation Model (ECHAM 4 - GCM): In a first simulation we use optimised rooting depths. These rooting depths can be seen as ones that are developed by the vegetation in equilibrium with climate. They are much larger than those currently used in global models, but are consistent to observations. A second simulation is performed where rooting depth in the tropics is reduced to 60 cm. The climatic changes associated with the different rooting depths are investigated in terms of direct effects (evapotranspiration and air temperature) and indirect effects (atmospheric circulation). The findings and the described mechanism form the basis for the second part (see Hagemann and Kleidon), where we investigate the changes in the hydrological cycle in more detail for a few large catchments. We conclude that rooting depth is an important land surface property, especially in the tropics. The removal of deep rooted vegetation in the tropics, for instance by deforestation, could have significant impacts on the local, regional and global scale.

EVAPORATION FROM A HUMID GRASSLAND CATCHMENT

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We determined the evaporation from a grassland catchment (16.5Ha) over one year from field experiments. Instrumentation included: a standard meteorological station; time domain reflectometry (TDR's); precipitation; streamflow and a class A pan. For the full year, evaporation accounted for 41% of precipitation. During the summer months, the Penman-Monteith evaporation was 95% of Class A pan evaporation.

LAND SUBSIDENCE AND HYDRODYNAMIC COMPACTION OF SEDIMENTARY BASINS

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Over the last decades, a great deal of attention has been paid to land subsidence due to groundwater abstraction, hydrocarbon production, mining and tunneling activities. By comparison, subsidence due to natural compaction has been a suppositious child. In order to gain insight into the importance of the latter process we have developed a hydrodynamic compaction model that combines Terzaghi's principle of effective stress with Darcy's law and which is driven by sediment loading. We present both a scale analysis of the model equations and numerical experiments which illustrate that subsidence rates can attain a significant fraction (>40%) of the long-term sedimentation rate and that compaction-derived subsidence is delayed with respect to sediment loading. Typical subsidence rates predicted by the model are of the order of 0.1 mm/yr, but may reach values in excess of 1 mm/yr under favourable conditions. It is shown that the response time of the compaction system can attain values of 10^5-10^7 years for sediment columns that consist of several kilometers of low permeable sediments such as shales. This would imply that, under these conditions, current land subsidence is the product of sedimentation that occurred as long as hundreds of thousands or even millions of years ago. Preliminary results of an application to the coastal area of the Netherlands are presented.

MODELLING OF HYDROLOGICAL CYCLE COMPONENTS IN THE NOPEX AREA

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A regional space-distributed hydrological model, ECOMAG, has been applied for simulation hydrological cycle characteristics in the NOPEX (NOrthern hemisphere climate Processes land-surface EXperiment) area (80x100 km), situated in the southern Sweden. In ECOMAG, a studied area is sub-divided into a mosaic of regular elements, each to be viewed as a landscape hydrological unit or Representative Elementary Area (REA). The minimum size of the REA has been defined on the basis of statistical analysis of the spatial data for the NOPEX area. The specific characteristics of topography, soil, vegetation and land use types for each REA on the grid 2 km for the whole NOPEX area were determined in a GIS framework. For each landscape unit the model describes the main processes of the land hydrological cycle: infiltration, thermal and moisture regime of soil, evapotranspiration, snow cover formation and melting, formation of surface, subsurface, groundwater and river runoff. The model was validated against runoff data for nine river basins in the NOPEX area for the period 1981-1995 as well as against special measurements of evapotranspiration, soil moisture, groundwater and synoptic runoff, performed during two CFEs in 1994-1995. Observed and simulated water balance components in the NOPEX area are compared and discussed.

ASSESSMENT AND DEVELOPMENT OF PEDOTRANSFER FUNCTIONS FOR SEMI-ARID SUB-SAHARAN AFRICA

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The application of process-based hydrological models requires the estimation of a number of soil hydraulic properties which are difficult, time-consuming and costly to measure. This would have severely limited the use of these models had it not been for the development of pedotransfer functions (PTFs). PTFs are regression equations which relate readily-available/easily measured soil physical and chemical data either directly or indirectly to soil hydraulic properties. The great majority of work in the development of PTFs has been in the USA and Europe and therefore the soils used have been American or European. The problem comes in trying to apply PTFs in other areas such as sub-Saharan Africa. This paper describes on-going work at a number of locations in Tanzania which is attempting to evaluate the ability of PTFs to accurately predict soil hydraulic properties. Results are presented which compare PTF-predicted soil hydraulic properties with those measured by a number of different techniques including the instantaneous profile drainage method and tension infiltrometer in the field as well as standard laboratory techniques. Results indicate that American and European PTFs do not reliably predict the hydraulic properties of the tested Tanzanian soils. The factors responsible for this and the techniques currently being considered for adapting PTFs for use in Tanzania are discussed.

A GENERALISED EXPRESSION FOR SOIL MOISTURE STORAGE CAPACITY DISTRIBUTION

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The distribution function introduced by Zhao et al. (1980) in Xinanjiang model to represent the variability of soil moisture storage capacity in a catchment has been widely acclaimed in literature. Improved rainfall-runoff modelling at various scale levels have emerged in recent years (Wood and Zaratarian, 1992; and Todini, 1996) incorporating this function. The proposed paper introduces a more generalised expression of this function considering the following aspects which are in consistence with the behaviour of natural catchments: 1) the possibility that a fraction of the catchment could be characterised by the same point values of the soil moisture storage capacity should be taken into account, 2) there may be two or more catchments having the same areal average soil moisture storage capacity, but characterised by different shapes distribution functions due to different soil characteristics of these catchments, and 3) it is more realistic that the soil moisture storage capacity within the catchments varies between a minimum and maximum specified point values with the minimum being equal to or greater than zero. In the present study, the expression for a generalised soil moisture storage capacity distribution function considering the above aspects are arrived at by adding only one parameter over and above the three parameters of Xinanjiang model.

ESTIMATION OF ENERGY FLUXES FROM THERMAL INFRARED, SPECTRAL REFLECTANCE, MICROWAVE DATA AND SVAT MODELLING.

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The ALiBi model, which is a Soil–Vegetation–Atmosphere Transfer model, was developed to simulate mass and energy exchanges between vegetation canopies, the soil and the atmosphere. In the present work, it was used in conjunction with remote sensing data in thermal, solar and microwave domains to assess energy balance of two soybean crops. Inversion of radiative transfer formulations were performed to retrieve model parameters: *-i)* canopy structure parameters (leaf area index and canopy height) from red and near-infrared reflectances; *-ii)* surface soil moisture from radar measurements (in C band) and *-iii)* plant water transfer parameters from thermal infrared measurements. Estimations of energy balance fluxes were in good agreement with measured values, in particular for a well developed canopy. A sensitivity study of the procedure showed that it was not necessary to know surface soil moisture and leaf area index with a good accuracy to obtain accurate energy balance fluxes. Conversely, the vegetation height must be known with a good accuracy.

EVALUATION OF THE RESPONSE OF SPRUCE FOREST ECOSYSTEM ON CLIMATIC CHANGES: RESULTS OF MODELLING EXPERIMENTS

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The future physical and chemical environment of forests will change. How forests will react to these new conditions is not known yet. In order to study the impact of possible climate change on forests, first of all, it is necessary to investigate the response of forest ecosystem on change of key environmental parameters (e.g. air temperature, moisture conditions, CO_2 contents in the air, etc.).
To estimate the possible response of a spruce forest ecosystem in the Solling hills (Germany) on climatic changes the multi-layer non-steady-state SVAT model (SLODSVAT) was used. In order to consider a wide range of possible future climatic changes 4 major scenarios for modelling experiments were chosen, describing the main possible shift of future climatic conditions: (*i*) the climate will be drier and warmer; (*ii*) the climate will be more wet and warmer; (*iii*) the climate will be drier and colder; (*iv*) the climate will be more wet and colder. All scenarios were examined at three various ambient CO_2 concentration in the atmosphere: 350 (current condition), 450 and 550 ppm.
The modelling results show growth of net CO_2 balance with increasing of ambient CO_2 for all scenarios. Maximal growth is obtained for dry climate scenarios. Transpiration (TR) and evapotranspiration (ETR) have similar trends: cold and wet climate will decrease, and warm and dry climate will increase total TR and ETR.

A TWO-LAYER MODEL OF NEAR-SURFACE SOIL DRYING FOR TIME-CONTINUOUS HYDROLOGIC SIMULATIONS

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A two-layer soil water balance model is developed to provide an efficient and robust description of land surface dynamics in response to atmospheric evaporative events. Soil, vegetation, and atmosphere are dynamically coupled under the assumption that soil moisture profiles approximately preserve similarity during simultaneous atmospheric drying and gravity drainage. The exfiltration flux at the land surface in response to the atmospheric evaporative demand is limited by relating the surface resistance to water vapor transfer in the Penman-Monteith equation to the near-surface soil status. In addition, the control of deeper soils on both exfiltration and drainage is expressed by performing a time compression approximation water balance over the entire drying profile and by scaling the obtained exfiltration and drainage fluxes to the near-surface soil layers. The reliability and robustness of the proposed formulation is evaluated with rates of evaporation calculated from measurements of the Bowen ratio and soil moisture data obtained from time domain reflectometry measurements for a bare soil field in the Zwalmbeek catchment (Belgium).

FIELD APPLICATIONS OF A VARIABLE PARAMETER MUSKINGUM METHOD

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A physically based Variable Parameter Muskingum (VPM) method was developed by Perumal (1994a) and its ability to route floods was studied using hypothetical floods (Perumal, 1994b). The proposed study demonstrates the practical utility of this method to route floods using flood data available for some reaches of the Murrumbidgee, Darling and Mitta Mitta rivers in Australia and for a specified stream network segment of the Tyne river in UK. The study illustrates how to estimate the routing parameters using the limited channel cross-section information and the wave speed-discharge relationship established for the routing reach. The ability of the method to reproduce the observed flood hydrograph has been evaluated using the Nash-Sutcliffe criterion.

COMPARISON OF LAKE EVAPORATION ESTIMATED BY ISOTOPE MASS-BALANCE, BULK-AERODYNAMIC & BOWEN RATIO METHODS.

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Evaporation from a shallow lake in central Sweden was estimated using oxygen-18 mass balance, bulk-aerodynamic and Bowen ratio methods, to access the feasibility of isotope method in Scandinavian conditions. The isotope method accounted for the isotopic non-steady state of lake-water. Oxygen-18 content i.e. ($\delta^{18}O$) of lake-water, inflows and outflow was measured on a weekly basis, where as in precipitation it was monitored daily. The lake level and discharge from the lake was also recorded daily. From a mast installed in the middle of the lake, wind speed profiles, temperatures of air and lake-water, relative humidity and radiation data was collected for the bulk-aerodynamic and Bowen ratio methods. Lake evaporation varied from 1.5 to about 5.0 mm/d during the experimental period. It was found that evaporation estimated by all the three methods agreed very well during most of the sub-periods and fairly well in three sub-periods. A sensitivity analysis of the isotope method was also done, where errors in the measurement of relative humidity, $\delta^{18}O$ of inflows and atmospheric moisture were simulated. It was observed that the isotope method is quite sensitive to variations in δ-values of inflows and atmospheric moisture. Variations in relative humidity had little effect on evaporation so long as humidity did not exceed 85%.

IMPACT OF DIFFERENT NUMERICAL COUPLING TECHNIQUES BETWEEN SURFACE AND ATMOSPHERE IN A GCM

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Land surface processes have a significant impact on near surface climate phenomena. The component of an atmospheric general circulation model (GCM), that is responsible for the representation of land surface processes, is the land surface scheme, which essentially represents the land surface energy and moisture cycles. Various different land surface schemes have been developed for use in GCMs that utilize very different parameterizations of these physical processes and lead to differences in the simulated climates. On the other hand, the numerical coupling between land surface and atmosphere can also have a significant impact on the model simulation.

Two versions of the ECHAM4 GCM are compared, one with semi-implicit coupling between land surface and atmosphere, the other with fully implicit coupling. A global simulation was performed with both models, using the same initialization and climatological sea surface temperatures. The results show that the coupling technique has an important impact on the simulated surface climate and water and energy cycles. These results are compared to an experiment with a third version of the ECHAM4 GCM, in which the SECHIBA land surface scheme is implemented in a fully implicit way. This allows one to estimate the relative importance of differences in land surface parameterizations and differences in surface–atmosphere coupling techniques.

DERIVATION OF FUNCTIONAL LAYERS IN A PODZOL TOPOSEQUENCE FOR SIMULATING CADMIUM TRANSPORT

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Undisturbed podzol profiles are very heterogeneous and contain multiple layers with significantly different functional properties. Layering will largely affect transport of contaminants from topsoil to groundwater. Cadmium mobility in acid sandy soils is mainly governed by the amount of organic carbon and pH of the soil solution. In layers low in organic carbon and pH the importance of soil physical properties on cadmium transport will become more pronounced. In this study pedogenetic layers of three distinct podzol profiles in a toposequence are characterised for physical as well as chemical properties. Profile results of organic carbon, pH, field-saturated hydraulic conductivity, van Genuchten parameters and solute transport parameters are used to derive functional layers. The derivation of functional layers and screening model results will be presented.

REAL-TIME FLOOD FORECASTING VIA COMBINED USE OF CONCEPTUAL AND STOCHASTIC MODELS

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Stochastic modelling of the simulation errors resulting from the off-line application of conceptual rainfall-runoff models is often performed in the context of real-time flood forecasting, in order to be able to predict such errors so allowing to improve the accuracy of the forecast. Although widely applied in the operational practice, such approach has not been extensively investigated in the scientific literature. This analysis is aimed to evaluate the benefits in discharge forecast accuracy that can be gained by this kind of approach and to provide some insights into the identification and estimation procedures of the optimal stochastic model to be applied when updating the forecasts. Application of linear ARIMA models, even in the fractionally differenced form, has been herein considered for some case studies referred to river basins located in Italy. The results have shown that the stochastic updating procedure is significantly worth performing when the lead-time of the forecast do not exceed a time threshold, which is expected to vary with the response time of the basin.

GEOPHYSICS FOR STUDYING THE DYNAMICS OF NEAR-SURFACE UNDERGROUND WATER IN MODERN URBAN CONDITIONS

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Dense town building creates serious problems for geophysical investigations. The dynamics of near-surface water here depend not only on season changes, precipitations or changes in base level of erosion but also on leakage from underground communications, breaches in stable structure of near-surface grounds, and extensive excavations, building and repair works. High-precision gravimetric monitoring can be applied to define non-tidal gravity changes associated with water accumulations in limited areas of the near-surface layer, flow directions as well as the following building damage. Electromagnetic sounding using ImpulseAuto® equipment created at the Siberian Institute of Geophysics (Novosibirsk, Russia) permitted to trace the base of the cultural layer, locate ground water accumulations, leakage from water communications and its direction. Non-tidal gravity changes helped to locate the natural reservoir of ground and technogenic waters negatively affecting the Suyumbeki Tower and former Governor's Palace situated on the territory of Kazan Kremlin. Electromagnetic sounding revealed fractures in water-resisting layers through which ground water flows from upper layers to lower those in an aeration zone. It was also possible to locate leakage sites and determine directions of technogenic water flows contributing to building destruction.

THE TRANSFORMATION OF DYNAMIC PARAMETERS OF OIL-CONTAMINATED SEDIMENTS THE NORTH EUROPEAN RUSSIA.

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The study of dynamic parameters of terrigenious material was carried out in subaqueous areas of North European Russia (Bolshezemelskaya, Malozemelskaya tundra) and coastal Barents sea including Pechora river deltha. The areas are characterized by extremely wide spreading of fluxes, lakes, marshes. This is the intensive exploited oil-gas Play. The geological survey, existence of pooled recoverable hydrocarbons are accompanied by the pollution of natural environments and upper lithosphere. The main oil-pollution is accumulated in soils and sediments of small flows. The periodic processes (high-flood, snow thaw) include the contaminated sediments in transfer. According the natural investigations the spreading range of oil-pollutions connected with terrigenious material can be highly essential.

The experimental work was based on the comparison of structural and dynamic characteristics of polluted sediments and the same sediments purified from oil-products. The average breaking and accumulated velocities for the sediments of different lithology with various concentrations of oil-products were determined. Parallely were determined : the character of interaction of mineral and oil parts (morfological forms of oil-contaminents), the quantitive and qualitative composition of oil-products in different size fractions of sediments.

The results of investigations allow to predict the distance of migration, possible zones of accumulation and the scale of oil-pollution in aquatic systems.

SENSITIVITY OF SURFACE FLUXES TO STRUCTURAL DIFFERENCES IN SOIL MOISTURE SIMULATION

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Two land-surface schemes, which differ only in the structure of the soil moisture prediction module, are compared. The first more complex model applies the Richards and heat diffusion equations for calculating soil moisture and temperature changes. The other, simpler model uses diffusion type soil moisture module and calculates deep soil temperature by the force-restote method. All other components (atmospheric and vegetation parametrizations) are identical. In test runs the Cabauw data set was used. The resulting differences are studied in terms of both the annual mean and seasonal changes of energy and water fluxes. The preliminary results suggest that deviations imposed by structural differences in soil moisture prediction modules are not more significant than the deviations imposed by the differences in some relevant parametrizations. The results are useful to understand soil physical processes and to formulate soil moisture and temperature prediction modules.

HYDROLOGIC MEASUREMENTS IN AN ALLUVIAL WETLAND

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Upstream from Paris, close to the confluence of the rivers Seine and Aube, the alluvial plain is inundated every year, resulting of flooding and/or upward movement of water in the alluvial aquifer. In those kind of environments, where surface water flows (horizontal and vertical) are combined with ground water vertical flows, hydrology is difficult to understand. The objective of our study is to investigate water circulation and specially vertical transfers during a rise and drop cycle on the base of measurements on a regularly inundated field.

The observational network may be defined as follows. A 10 m by 10 m square is isolated using plastic sheets driven in the soil. An open pipe lying on the soil and crossing the plastic sheet on one face of the square allows hydraulic equilibrium between inside and outside water. Both water flow through the pipe and water level in the square are recorded. Colorado tank is used to determine net precipitation. Hence, a water balance on the square allows to point up and quantify the vertical transfers (upward or downward) masked by the about 30 cm of inundating water.

To extend the investigations to the 3D movements below the soil surface, the installations are completed by a plan of 10 piezometers at different depths between 2 m and 10 m (chalk substratum) near the square. The unsaturated zone is studied using a set of tensiometers inside the square.

ESTIMATING THE ROOT-ZONE SOIL MOISTURE FROM REMOTE SENSING OBSERVATIONS

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The objective of this work is to develop a methodology for estimating the soil moisture in the root-zone from remote sensing (RS) observations in the thermal infrared and microwave domains. The work is based on two intensive field experiments at Avignon, in 1989 and 1990 over crop canopies. The measurement data sets include heat and water fluxes, soil water balance, soil and vegetation characteristics, thermal infrared measurements and also radar remote sensing data at C-band in 1989. The present study proposes a synthetic coupling between the remote sensing data and the simulations of the surface fluxes by ISBA, which is the surface scheme of the weather forecast model at METEO-FRANCE. The data in 1990 are used to calibrate two input parameters of ISBA: the vegetation surface resistance to water exchanges and the soil water diffusivity. A methodology for assimilating the microwave and thermal infrared remote sensing data in ISBA is analysed. The feasability of the assimilation process is demonstrated and the methodology makes it possible to estimate the requirements, in terms of temporal repetition and measurement accuracy of the RS data, for retrieving the crop soil water reservoir.

The Role of Interception in the Water Budget of Spruce Stands in the Eastern Ore Mountains /Germany

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In the Eastern Ore Mountains large areas situated at the ridge are deforested mainly due to high levels of atmospheric sulphur dioxide. For the quantification of element budgets the water budget of small forested experimental watersheds is recorded, one situated in the upper, the other in the lower mountains. Interception is the major part of forest evapotranspiration in humid climates due to their low aerodynamic resistances. Interception was measured by standard experimental design and made up nearly 50% of open-field precipitation in summer showing typical dependence on rainfall intensity. The RUTTER interception model was modified taking into account different layers of the canopy and tested with throughfall and evapotranspiration rates measured by eddy covariance/energy balance (ECEB) method. The ECEB evapotranspiration was compared to the difference of precipitation and discharge of both watersheds. The water budget of the ridge watershed showed a marked difference explained by fog interception as important additional input for fog-rich sites. The high atmospheric coupling of spruce forests could be seen by near-equality of evapotranspiration of both sites despite an altitudinal gradient of 360 m. Especially in autumn an 'oasis effect' happens, where the flux of sensible heat is reversed to the canopy enabling evapotranspiration to exceed net radiation. All these findings show the importance of proper measurement and modeling of interception for water and element budget studies of forested watersheds.

HSA6 Hydrology and soil processes

01 Recent advances in tracers in vadose zone hydrology

Convener: Tyler, S.W.
Co-Conveners: Edmunds, W.M.; Flury, M.; Scanlon, B.R.

APPLICATION OF SORPTIVE TRACERS WITHIN WASTE DISPOSALS

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The transport processes within a municipal waste disposal were studied using both sorptive and nonsorptive fluorescent tracers (uranine, eosine, sulforhodamine B and naphthionat). Their properties relevant to the transport within the saturated and unsaturated zone of disposals were characterised. The tracers showed a range of diffusion coefficients and sorption parameters comparable to commonly occuring contaminants. Furtehermore they were found to be stable in leachate water under anaerobic and aerobic conditions. The tracers were applied at a well described subsection of the waste dump with unsaturated flow distances of 10 m. The outflow of this subsection was monitored on-line, samples were taken every hour. A strong relation between tracer transport and precipitation could be observed. All tracer occurences could be tracked backward to heavy rainfall or melting snow. The time gap to precipitation events was rather short ($\approx$ 1 d). The overall recovery rates were far below 1 %. Despite of their different properties, the tracers showed similar transport behaviour. The investigations led to a principal model of water and contaminant transport within disposals. The common flow paths are small pores and fractures within the disposal ith transport velocities beyond mm/month. Here leaching, sorption and other matrix interactions take place. After heavy rainfall larger fractures and voids are filled, leading to a fast transport (m/day). Following a first phase where mobile contaminants are removed from these flow paths, this flow leads to a dilution of the leachate waters at the base drainage.

A MULTIPLE TRACER TECHNIQUE TO IDENTIFY THE PRESENCE OF PREFERENTIAL FLOW IN SOIL

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Identifying the presence of preferential flow is difficult when using tracers that do not show good color contrast with the soil and when using a single tracer for breakthrough curves. A method to characterize the presence of preferential flow is presented. The concept is that the ratio of the retardation factors of two dyes measured from breakthrough curves should be the same as measured from batch studies if the soil does not have preferential flow. The concept was tested in laboratory on repacked soil columns that contained macropores of various continuity and tortuosity levels. Simultaneous breakthrough Rhodamine WT, and the FD&C Blue #1 showed that the ratio of the apparent retardation factors of Rhodamine to Blue (R'_{Rwt}/R'_{Blue}) was lower compared to the ratio of the retardation factors of the same tracers from batch studies (R_{Rwt}/R_{blue}) if the soil contained macropores that were open at the soil surface. For soil columns where macropores were tortuous, the ratio (R'_{Rwt}/R'_{Blue}) increased with an increase in macropore tortuosity. In soil columns where there were no macropores, the ratio R'_{Rwt}/R'_{Blue} was the same as R_{Rwt}/R_{blue}. This suggest that the method could be a useful index to identify the presence of preferential flow.

Field investigation of the processes of highly mineralized brine migration in the unsaturated zone

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For studying the mechanism of brines migration in unsaturated zone in the oil field, field investigations have been carried out, that were of a preliminary character. Field investigations were aimed at modelling the processes of soil salinization with brines and weakly mineralized artificial solutions to determine transporting and migration parameters and also modelling the process of soil gypsum application for neutralizing brines effect on them. Experimental studies were carried out in two sites with an area of 1m2 on the surface to the left and to the right from a pit 1.5 m deep, 1.5 m wide and 3.0 m long. Margins of the sites have been thoroughly banked up to prevent overflowing of solutions over the site limits. One site was for industrial brines of chloride - sodium composition (mineralization being 137917 mg/l, density - 1.176 g/cm^3), the other was for an tracer solution of chloride - sodium composition (mineralization being 1893 mg/l, density 1.0 g/cm^3. The volume of solutions being introduced was equal to three volumes of pore space in the filtration body. Soil sampling for water extraction have been taken from pit walls. The experiment lasts for two days.

Preliminary data processing of brine and trace solution introducing has shown that brine filtration intensity is twice as large as trace solution. Here, it should be considered, that the brine used in the experiment has a minimal mineralization and density, if compared with the most widely spread types of industrial brines, characteristic for this oil field. Thus, more mineralized and dense brines will filtrate through unsaturated zone even more intensively. Under brine migration in the upper profile (0 - 0.2 m) maximum salinization began to be formed at the end of the first day, and during the first day soils were not saline, but by the end of experiment maximum salinization has been formed in this layers. In the second profile (0.2 - 0.4 m) soils were not saline for 10 hours, maximum salinization has been formed by the end of the first day, similar process was observed in the lower profiles, but maximum salinization began to be formed in them after 14, 19 hours. Under migration of trace solutions, quite a different picture was observed: all the soil layers gradually became saline during the experiment and maximum salinization has been formed at a depth from 0.2 to 0.4 m. Experimental data have confirmed our assumption on pressing falling the brines through the upper part of the saturated zone.

FLOW THROUGH FRACTURES IN VADOSE CHALK

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Flow and transport processes through fractures in the vadose zone were investigated in field experiments conducted on natural, relatively undisturbed, through-going fractures in chalk at an arid region in the northern Negev Desert, Israel. The experimental field method incorporates two main components: a) percolation ponds installed sequentially along a chosen fracture; and b) a compartmental sampler specially designed to collect the effluents drained from the ponds via the fracture. Combined with a multi-tracer test, this method provides exclusive information on hydraulic behavior, transport phenomena, and flow trajectories within the fracture plane. Field experiments indicated that significant active-flow pathways prevail along the main fracture plane in dissolution canals. These canals usually appear where the main fracture is crossed by secondary fracture planes. As such, large portions of the fracture-plane surface are not hydraulically active. Flow rates into and out of the fracture openings did not reach steady state, or a clearly defined development tendency anywhere within the fracture plane during a five-day experiment, whereas the water head in the percolation pond was kept at a constant level (5 cm). Consequently, flow paths within the fracture plane, and turbidity of the drained effluent did not stabilize. These results influence modeling approaches regarding fracture flow in unsaturated chalk in arid regions.

USE OF DYE TRACERS FOR THE IDENTIFICATION OF SOLUTE TRANSPORT IN THE VADOSE ZONE

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Dyes are useful tracers to stain the flow pathways of water and solutes in the vadose zone. The application of dyes to the soil surface and the subsequent excavation and examination of the trench face reveals a detailed picture of the often highly irregular flow patterns encountered in porous media, in a spatial resolution that currently no other sampling technique can achieve. Dyes have been used to stain flow pathways already for decades. Many different dyes have been used as tracers. Recently, advances have been made in respect to quantify dye concentrations in soils. New image analysis techniques have been introduced and show promising results. This presentation reviews the use of dye tracers to stain flow pathways in the vadose zone. The different dye tracers used in the past are discussed and new analysis techniques are demonstrated.

MULTIPLEXED FOUR-DIMENSIONAL FIBER-OPTIC FLUORESCENCE FOR IN-SITU DETECTION OF SOIL AND GROUNDWATER TRACERS

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In-situ measurements are of utmost importance for hydrological characterization and for rapid diagnosis of contaminated sites. A fiber-optic based laser system has been developed to allow in-situ analysis of fluorescent chemicals at different locations. The system is divided into two main modules mounted on a mobile rack. The central one contains the excitation source (a Nd:YAG pulsed laser) coupled with a Raman shifter and 8 fiber-optics up to 50 m length, and the detection module including an intensified gated CCD camera connected to an imaging spectrograph. The system allows four-dimensional fluorescence analysis, i.e., signal resolution in terms of different excitation and emission spectral features, and different fluorescence decay times. This facilitates a selective identification of multiple fluorophore tracers and their discrimination against background fluorescence of natural organic matter. Multiplexing of the 8 fiber sensors allows simultaneous analysis at different locations and monitoring of tracer plume movement. The performance of the system is currently tested in a soil monolith comprising 18 elemental cubes filled severally with uniform soil media generating geometrically regular heterogeneity. Results of time-resolved fluorescence measurements of mixtures of humic substances and fluorescent chemicals are reported.

CHARACTERIZATION OF INFILTRATION IN UNSATURATED POROUS MEDIUM USING FLUORESCENCE EFFECTS

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Characterization techniques such as disc infiltrometers and Guelph permeameters are commonly used for the determination of soil hydraulic properties. The analysis of the measurements performed with these devices should take into account the multi-directionnal flow effects. However, the phenomenon of three dimensional infiltration is difficult to measure with the classical devices (TDR or neutron probes combined with tensiometers), as the evolution of both volumetric water content and soil water pressure have to be monitored simultaneously at different depths and locations. Moreover, the use of various probes would significantly disturb the geometry of the flow volume.We propose in this study an experimental non-destructive laboratory method for the observation of axisymmetrical infiltration in an unsaturated porous medium. The method is based on the visualization of the infiltration phenomenon by the use of fluorescence. It allows to observe with great accuracy the evolution of the wetting front during the infiltration phase. Simultaneously, we propose an image analysis based on morphological binary mathematics for the determination of the flow parameters.

A MULTIPLE TRACING EXPERIMENT TO DETECT FLOW-PATHS IN FOREST SOILS

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For a correct interpretation of the nitrogen budget of forested ecosystems it is necessary to have information on water flow in the macroporous forest soils. To support a study on nitrogen cycling at a larger scale, we investigated the flowpaths of water in two sloped plots ($15m^2$) with distinct soils. The drier plot is covered with a raw humus top soil and has a partly oxidized, well structured subsoil. The wetter plot has a muck humus top layer and a fully reduced clay layer with macropores and old tree roots up to -30 cm. Before the application of the tracer cocktails the plots were continuously irrigated (6mm/h during 12 hours) to obtain steady flow conditions. The runoff of the soil plots was measured in three different depths and samples were taken flux dependently. Three anionic and four dye tracers were applied as pulses into the subsoil and at the surface. We tested the hypothesis of preferential flow in both the subsoil and in the humic topsoil. Breakthrough curves of tracers injected directly into the subsoil were compared with those of tracers applied at the soil surface. Preliminary results favour the hypothesis concerning the flowpaths in the gleyic subsoil. However, preferential flow in the topsoil could only be observed after tracer applications with a high application rate. There was no evidence for preferential flow of tracers applied at the surface at moderate application rates.

APPLICATION OF CHLORIDE AND OXYGEN-18 AS VADOSE ZONE TRACERS UNDER TEMPERATE CLIMATIC CONDITIONS

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We studied the movement of soil water through a deep vadose zone of a sandy hill in the central part of the Netherlands. The behaviour of soil water was tracked by monitoring soil water fluctuations and changes in the environmental tracers oxygen-18 and chloride in vertical profiles at test sites with grassland, heathland and forest vegetation. The chloride profiles show high concentrations in the root zone, sharply dropping below the root zone to lower and rather constant values. The average oxygen-18 composition shows that, in spite of a moisture deficit during summer, part of the summer rainwater infiltrates to below the root zone. The decreasing chloride values and the oxygen-18 composition are explained by preferential flow of less concentrated rainwater bypassing the root zone quickly. Oxygen-18 exhibited a clear seasonal fluctuation below the low vegetation covers from which the soil water infiltration rate could be calculated. This clear seasonal pattern suggests that below the root zone, the soil water movement is dominated by diffuse flow. The profiles from both chloride and oxygen-18 show that the soil water flow mechanism is best described by preferential flow combined with diffuse flow in the root zone and diffuse flow in the percolation zone.

RADIOACTIVE TRACERS FOR THE IN SITU AND LABORATORY DETERMINATION OF THE HYDRAULIC PROPERTIES OF SLOWLY PERMEABLE POROUS MATERIAL

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The knowledge of the hydrodynamic characteristics of slowly permeable soils becomes a major concern for both soil physics and geotechnics, as regards to environmental protection and waste-repository sites management. Two methods of determination of these characteristics, on the field and in the laboratory, are described and analyzed, which involve low or mean-life radioactive tracers.
The field method is based on the injection of 99mTc in a double-ring under a constant ponded head. An accurate in-situ estimation of the unsaturated water flux is thus obtained within a few hours.
The laboratory method studies the diffusion and the permeation of tritiated water in a soil sample, under various boundary conditions. Long-time experiments give information on both the unsteady and steady hydraulic properties of the sampled material.
In order to compare these methods one to the other, field experiments were conducted on a natural silt and a mixture of fine sand and bentonite. Samples were then taken and tested in the laboratory. Excellent agreement was obtained between field and laboratory results. The laboratory technique could then be used to reproduce and/or predict field experiments.

ANALYSIS OF CHLORIDE MASS BALANCE IN A FIELD LYSIMETER

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The chloride mass balance method has been widely applied to estimate the soil water flux and recharge in arid environments. In this work, we analyze chloride concentrations in soil water and drainage water from a long-term lysimeter facility located on the Hanford Reservation in eastern Washington, USA. The lysimeter is filled with sandy soil and had had observable drainage for the last 16 years. Soil samples, collected in 1996 from ten depths from the land surface to 7.16 m display chloride concentrations ranging from 4.5 to 6.9 mg/L. Recharge rates calculated from these soil water concentrations are approximately one-fifth those currently observed based on drainage measurements from the lysimeter. Drainage water chloride concentrations are also approximately one-fifth those observed in bulk soil samples.

These data suggest that despite the two pore volumes of drainage occurring over the last 16 years, a portion of the pore space has not been fully leached. Numerical analysis of both fully advective and mobile/immobile transport models will be presented to shed light on the processes responsible for the observed differences in calculated and observed fluid fluxes.

RECHARGE ESTIMATION OF THE CONEJOS-MEDANOS AQUIFER SYSTEM, NORTHERN MEXICO

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Sixty four samples from 1 to 58 m depth of the unsaturated zone were analyzed for moisture content, Cl, (2H and NO3-N. The borehole is located near Ciudad Juarez, northern Chihuahua. The profile sediments are rather heterogeneous with a predominance of fine sand, some clay and silt and thin layers of caliche. Samples were obtained by dry percussion and contained in sealed glass jars. The interstitial water was extracted by elution; chloride and nitrate were determined by automated colorimetry while deuterium by direct reduction. The analytical results show that the mean chloride concentration of the unsaturated zone profile is 850 mg/l (range 61 to 4,556 mg/l), for (2H is -56((-71 to -34() and for NO3-N is 4.28 mg/l (<0.11 to 10.57 mg/l). Considering a mean average precipitation in the area of 230 mm/year and a chloride rain content of 1 mg/l, we estimated a net palaeorecharge in the area of about 0.27 mg/l with a probable time scale profile of 17,000 years. These results are part of the current IAEA - Coordinated Research Programme Programme "Isotope based assessment of groundwater renewal and anthropogenic effects in water scarce areas".

MEASURING WATER FLOW AND SOLUTE TRANSPORT UNDER NATURAL BOUNDARY CONDITIONS IN A LOAMY SOIL PROFILE

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Some experimental results of a solute transport experiment under natural boundary conditions in a loamy soil profile are presented. The objectives of this research are (i) to investigate water flow and solute transport processes under natural conditions at the field-scale, and (ii) to obtain detailed data for the validation of different simulation models. Along a transect of 6.5 m and at 5 depths (to 1 meter depth), 60 coated and 60 uncoated time domain reflectrometry (TDR) probes are installed. The TDR probes measure frequentely both resident solute concentrations and water contents. To calibrate the TDR probes, small soil samples were taken and calibration experiments are performed in the laboratory. In addition, 60 tensiometers and 15 temperature probes are installed to measure pressure heads and temperatures in the soil. All measurements are done using an automated system which provides a dataset with high resolution in both time and space. Top boundary conditions are measured with vertically installed TDR probes. Passive capillary samplers (PCAPS) are installed at two depths to measure the water and solute flux. In this way, the importance of macropore flow is investigated. Time series of resident concentration (TDR) and flux concentration (PCAPS) are compared with each other.

PARTITION PREFERENTIAL FLOW BY SEQUENTIALLY APPLYING CONSERVATIVE TRACERS

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Leaching of adsorbed contaminants through preferential flow paths in agricultural soil has not been systematically studied. To gain a better understanding, five conservative tracers - bromide, chloride, 2,6di-fluorobenzoic acid (2,6DFBA), o-trifluoro-methyl -benzoic acid (o-TFMBA), and penta-fluorobenzoic acid (PFBA) - were applied to tile-drained plots in New York, Indiana, and Iowa and the tile outflow was monitored. The fields were irrigated twice for 10 hrs with an intensity of 3 mm/hr. Four tracers were applied during the first event at 1, 2, 4 and 6 hrs after the start of rainfall. The fifth tracer was applied just before the second rain four days later. The results between the three sites were surprisingly similar: The tracers applied 4 and 6 hrs after the start of the rain was detected in the tile line (at 80 cm) less than an hr after their application with total mass recoveries of 10-20%. The tracer applied at 1 hr had a travel time of approximately 4 hrs and only 4-6% of the mass was recovered in the tile outflow. The results indicated that sequentially applied tracers can partition preferential flow: We found that as soil surface became wetter, not only more water will move through preferential flow paths, but water will also move faster through the larger and/or more continuous preferential paths.

RADIOACTIVE TRACER TECHNIQUES USED IN SOIL HYDROLOGY

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Because of the ease and speed of measurements, radioactive tracer techniques are a promising tool for soil hydrology. They serve for detailed investigation of water flow and solute transport in the unsaturated zone of soil. One type of measurement, obtained from the Geiger-Mueller detector placed at the preselected depth, represents concentration distribution over time. The other type of measurement, obtained by scanning the observation probe using the same detector, represents concentration distribution over depth. In both types of measurement, the counting rate is considered to be proportional to the tracer concentration. Using the scintillation detector, transport of several solutes with different mobility could be investigated. From a tracer leading edge displacement in the soil matrix, the bypassing ratio can be calculated in the representative elementary volume of a macroporous soil. The bypassing ratio can be used to estimate the irrigation and fertilizer efficiency and to predict groundwater vulnerability to various pollutants. Radioactive tracer technique can also serve in batch experiments or combined batch-column circulation experiments for determining the sorption of solutes by soils. Solution is spiked with proper radioactive tracer and the amount of isotope disappearance in solution is measured using scintillation counting.

CADMIUM TRANSPORT IN A STRUCTURED LOAMY SOIL

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The Danubian Lowland, situated in the south-west part of Slovakia, is a large (1260 km^2) agriculturally utilized area. A shallow underlying aquifer contains about 10 km^3 of freshwater. In this decade, an increase of groundwater vulnerability to cadmium has been noticed in that area. The aim of this study was to give evidence for a deep Cd penetration and estimate the maximal portion of Cd which moves preferentially along macropores in a loamy soil. Tracer measurements started at the site Kráľovská lúka (Bodíky) after 17-days lasting warm and rainless period resulting in a crack formation and, thus, the worst conditions for groundwater environment were simulated. The first measurement was made immediately after ponding infiltrations of 1 cm of water marked with $^{115}Cd^{2+}$ and 13 cm of pure water. Relative Cd concentration distributions over depth were obtained by scanning the observation probe using G-M detector. Considering Cd adsorption only and solute transport in the soil without macropores (retardation factor R_{Cd} = 670), all the Cd should be observed in the top 10 cm layer. But the tracer distributions have shown that more than 40 % of applied $^{115}Cd^{2+}$ penetrated deeper due to preferential flow in macropores. The second measurement followed after 15 days, in which 25.4 mm of rainfall was the cause of additional Cd displacement.

UNCERTAINTIES IN ESTIMATING WATER FLUXES AND DATING PORE WATER IN AN ARID UNSATURATED SYSTEM

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Accurate estimates of water flux and residence time in unsaturated systems are critical for contaminant transport in arid regions. The main source of uncertainty is that associated with the conceptual model used to interpret the tracer data and the validity of model assumptions. Uncertainties in flux and age estimates based on environmental tracers were evaluated using tracer data from basins in the Chihuahuan Desert in Texas (USA). Chloride concentrations in pore water were evaluated using the chloride mass balance method. High chloride concentrations in interdrainage areas (mean 784 to 4330 g m^{-3}) indicate low water fluxes ($\leq$ 0.5 mm yr^{-1}) below the upper 2 m in interdrainage areas and long residence times (32,000 to 156,000 yr at ~ 25 m depth). Low chloride concentrations in drainage areas (mean 30 to 600 g m^{-3}) indicate higher water fluxes in drainage areas. Long residence times for water in interdrainage areas were corroborated with data from radioactive decay of ^{36}Cl. There are a variety of assumptions associated with the chloride mass balance model such as one-dimensional, vertically downward, piston flow (i.e., no preferential flow or dispersion) and constant chloride deposition. Each of these assumptions was tested using information from other tracers such as ^{3}H, $^{36}Cl/Cl$, ^{2}H, and ^{18}O and soil physics data. Analysis of the tracer data indicates that most of the assumptions are valid in interdrainage areas; however, many assumptions are invalid in drainage areas such as playas. This study underscores the importance of critically assessing model assumptions when evaluating tracer data.

INTERACTION OF SURFACE- AND GROUND WATER IN HEADWATERS OF THE LESSER CARPATHIAN REGION

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The paper deals with an analysis of interaction between surface- and groundwater in the Lesser Carpathian region. The analysis was based on the data monitored by IH SAS weekly (fortnightly) during the period 1991-1995. In the samples of rain-, surface- and groundwater, the following chemicals were analysed: nitrate, nitrite, ammonia, sulphate, chloride, phosphate, as well as pH. To determine the interaction between surface and groundwater, the chloride and the total nitrogen was used as a tracer. The maximum nitrate concentrations in surface water were found in February - April, the minimum ones in July - October. In groundwater, the occurrence of the extreme values was delayed for 120 - 150 days in the dry year 1992/93, while in the wet year 1993/94 the delay was only 30 - 60 days. In a dry year, the penetration of nitrates into groundwater is slower and weaker than in a wet year. The mean annual nitrate concentration in groundwater was 33.6 mg.l^{-1} in a dry year and 44.6 mg.l^{-1} in a wet year.

AN INEXPENSIVE FLOW-THROUGH FIELD FLUOROMETER FOR TRACER TESTS

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In order to simplify sampling dye tracers in water streams without having to invest money in expensive systems, we developed a rugged, highly sensitive flow-through field fluorometer. This apparatus was tested successfully for 2 years in the field with fluorescein and sulforhodamine. The submersible part is connected to the digital data logger.The data is written to a standard PC-compatible PCMCIA memory card allowing 2 weeks of unattended recording at 1 sample every 4 minutes or 14 hours at 1 sample every 10 seconds. A sensitivity as low as 0.05 ppb is achieved routinely with fluorescein (wide dynamic range: 16 bits). Simultaneous concentration measurements of 2 tracers is possible, at the expense of reduced sensitivity, however. The apparatus can also be advantageously used in the laboratory, where discrete water samples are measured very quickly.

TAGGED DNA-MOLECULES AS TRACERS IN HYDROGEOLOGY

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DNA-tags offer new features to tracers, where qualitative detection of individual tracers emerging from different sources has enormous potential to assist many aspects of pollution studies. The nature of nucleic acids as carriers of genetic information makes them suitable for carrying a wide variety of information. Alpha-numeric information containing specifications like names, dates, batch numbers, etc. can easily be defined as a DNA sequence. ID-tag designed DNA-molecules are chemically synthesised and applied to the substance to be labeled. Detection and reading the information content is carried out by the polymerase chain reaction (PCR), a method widely used in biomedical research, forensic medicine, diagnostics, etc. Results from a series of DNA-tag injections under the bottom mudlayer of a small lake (Puttjern outside Oslo) show that DNA-tags could be demonstrated at certain loci in the railway tunnel Romeriksporten, ca. 70 m below the small lake . The DNA-tags were strongly diluted, but could still be both detected and read. One explanation for the successful use of naked DNA molecules is that the tags have to a large extent been exposed to pure water, with little or no organic material. Laboratory experiments to test the stability of DNA tracers in the unsaturated zone is under completion at the Department of Geology, University of Oslo. A field study at a lysimeter trench is initiated with the aim to identify preferential flow in the unsaturated zone by the use of DNA tracers along with conventional tracers and will be carried out in the first half of 1998.

PREFERENTIAL FLOW AS INDICATED BY BRILLIANT BLUE

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An often-encountered problem in agricultural areas is rapid transport of pesticides and fertilizers through cracks and fissures by preferential flow. This transport is several times higher than the average rate through the average soil matrix. Field investigations regarding preferential flow were conducted within an EU cooperation (HYDROMED: Research program on hill reservoirs in the semiarid Mediterranean periphery) to reveal consequences of this phenomenon. A 20-year rainstorm was simulated using a rainfall simulator and water mixed with dye. Vertical sections of 2.5-cm thickness were excavated and photographed. The results showed that different physiographical areas (nose, slope, and hollow) of the catchment displayed significantly different response to the infiltrating dye. Nose and hollow areas exhibited largest susceptibility to preferential flow. Here infiltrated dye was transported to the greatest depths. Nose areas showed a greater horizontal dye distribution in the upper 30-cm as compared to hollow areas. Slope indicated a similar dye distribution as nose areas, but with less deep cracks and fissures. The results show that different parts of the catchment have different properties regarding preferential flow. Possible results from dye experiments can be used to delineate areas of different susceptibility to preferential flow within the catchment to be used in model simulations.

Non-distructive investigation of the root zone with help of a Deuterium-tracer

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Rising atmospheric CO_2 concentrations have a direct impact on the water budgets of forest ecosystems. This might be due to reduced stomatal conductance, raised leaf area index or enhanced root growth and thus improved water supply. In a long term lysimeter experiment the water balance of young mixed beech-spruce forest ecosystems is determinded weekly. To be able to determine CO_2 induced differences in root water uptake without disturbing these ecosystems a deuterium tracer was applicated on 8 out of 32 lysimeters. After two month soil cores were taken down to 75 cm depth and root mass, water content and deuterium concentration was determined. First analysis shows a slower transport and less regained tracer under CO_2 treatments compared to non CO_2 treatments. Especially in the middle parts of the profile less tracer was found. In a further analysis it will be tested if this feature can be correlated with the root distribution.

PREFERRED FLOW PATHS IN A DRAINED GRASSLAND PLOT

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We studied lateral preferential flow into a tile drain in a multitracing experiment on a slightly sloping plot of 20 by 7.3 m. Various tracers were applied simultaneously at different lateral distances from the tile drain. We sequentially applied three different tracer combinations: conservative tracers (HDO, Br, Cl), fluorescent dyes (Amino-G-Acid, Sulforhodamine B, Brilliant Sulfaflavine), and two dye tracers (Brilliant Blue FCF, Acid Red 1) to stain the infiltration paths. During the experiment, the water table rose close to the soil surface in the center of the plot. Outflow was not restricted to the tile drain. Most of the water seeped out from two 3 m wide profiles excavated at the lower and the upper ends of the plot. The tracer breakthroughs demonstrated rapid vertical as well as lateral transport. However, the stained infiltration patterns did not reveal indications of lateral preferred flow paths. Numerical simulations demonstrate that the uneven outflow behavior from the upper and the lower profiles is hard to reconcile with the high water table in the center of the plot unless fast lateral transport occurred close to the soil surface. The results demonstrate that the flow paths in the plot can only be studied properly if their 3-dimensionality is taken into account. The understanding of the flow paths in the plot is strongly enhanced by the use of methods giving complementary information: conservative tracers applied at different locations, dyes to stain flow paths and measurements on the spatial distribution of outflow and of the water table elevation.

OVERVIEW OF INERT TRACER EXPERIMENTS TO CHARACTERISE TRANSPORT PROPERTIES OF SOME BELGIAN SOILS

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Leaching experiments were carried out in a range of soils with different texture: two sandy soils, a sandy-loam, a loam, and two silt-loam soils. During a leaching experiment, the replacement of the initial soil solution by a tracer solution ($CaCl_2$), was monitored at several depths in the soil profile using time domain reflectometry (TDR). Time series of in-situ measured tracer concentrations were used to identify an appropriate transport model (convection-dispersion, stream tube model, or mobile-immobile model) and the model parameters. All experiments were carried out in undisturbed soil monoliths (0.3-1.0 m I.D. and 1.0 m length) or in a field plot where solute concentrations were measured along a 8 m long transect. For the loam soil, a comparison between the field- and column-scale (0.3-m I.D. and 1.0 m) experiment revealed that field-scale solute transport could be predicted relatively well from transport measured in the monoliths. In all soils, the solute dispersion increased largely with increasing flow rate. The dispersion was the smallest in an intermediate textured soil (sandy-loam). In other soils, the dispersion was larger either due to preferential flow through large pores (cracks, worm holes, decayed root channels) (fine textured soils) or due to funnelling flow resulting from unstable wetting fronts or local differences in soil texture (coarse textured soils).

COLLOIDAL PARTICLES AS NATURAL TRACERS FOR PROCESSES IN UNSATURATED FRACTURED CHALK

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Void geometry of natural fractures is generally considered stable over short periods of time. Our research demonstrates that natural fracture surfaces of chalk can be modified rapidly as a result of intermittent flow. A series of flow experiments conducted in customized flow-cells containing coated and uncoated surfaces of naturally fractured chalk showed that the topographies of fracture surfaces changed by hundreds of microns during intermittent flow (hours) of rain water. Changes resulted mainly from the detachment of Brownian-particles from the fracture surface. Natural surface coating significantly increased the amount of particles detached from the fracture surface. Alteration between percolation of industrial wastewater and synthetic rainwater along the fracture surfaces increased both the surface subsidence and the fraction of large-size aggregates detached from the surfaces. These processes, observed in the laboratory, were also documented in the field. According to our observations, (1) void geometry of unsaturated fractures in chalk can change significantly over short periods of time, primarily as a result of particle detachment; and (2) interaction with industrial wastewater may eventually lead to the collapse of the fracture surface. Some of the particles may clog the hydraulic aperture of the fracture in critical necks and change the flow-channels within the fracture. Conversely, some of the detached Brownian particles may eventually reach the saturated zone and facilitate contaminant transport.

COLLOIDAL PARTICLES AS NATURAL TRACERS FOR PROCESSES IN UNSATURATED FRACTURED CHALK

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THE USE OF FLUORESCENT MICROSPHERES AS TRACERS IN THE UNSATURATED ZONE OF THE CHALK

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The aim of this investigation was to determine whether particulate matter could penetrate a significant thickness of unsaturated Chalk. The simple test described here used fluorescent microspheres of three diameters (1, 6 and 10 μm) and bacteriophage as particulate tracers as well as lithium bromide as an ionic tracer. The test was not designed to determine under which natural conditions such transport would occur, merely whether it was possible at all. To give the best chance of success, the soil was removed from the 7m x 7m site exposing a bare chalk surface. The unsaturated zone at the site was some 20m thick. The profile was 'wetted-up' by irrigation until a response was seen at the water table. The tracers were then applied to the exposed Chalk surface and the water table was monitored by sampling from a borehole in the centre of the plot. The site was irrigated lightly during the sampling period. Some months after the application of the tracers two cored boreholes were drilled within the site and core samples were analysed for the presence of the tracers. Bacteriophage and the 6 μm spheres were detected at the water table during the sampling from the borehole. The core samples revealed that the larger spheres and most of the smaller spheres had been 'held-up' at discrete levels within the profile. These levels correlated with low permeability features within the core.

PREFERENTIAL FLOW IN A SMALL AGRICULTURAL CATCHMENT: FIELD STUDY AND UPSCALING CONCEPT.

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Infiltration patterns produced by dye tracer experiments are often used to classify the infiltrational behaviour of small plots into categories like "preferential" or "classical". The decision whether an infiltration pattern is preferential or not, is mostly made by the experimentator in a pure descriptive way. In order to find out which combinations of initial and boundary conditions (e.g. moisture, soiltype etc.) lead to preferential flow it is necessary a) to form groups of similar infiltration patterns in an objective way and b) to find significant dissimilarities between the initial and boundary conditions which may explain the partitioning of the infiltration patterns into the different groups. Infiltration patterns from 14 different field sites at the weiherbach-catchment may be represented by some simple statistical parameters and divided into three infiltration categories with a cluster analysis. The partition into the three categories may be explained by differences in the initial and boundary conditions the with a disicriminant process. The procedure works for dye patterns and for bromid data respectively. In principal the influence of data types like morphological data (e.g. soil type) on a nominal scale or interval-scaled parameters (e.g. moisture) may be taken into account. The forcast of the infiltration category of a new field site for different initial and boundary conditions with a discriminant function leads to a new upscaling concept for infiltration.

HSA6 Hydrology and soil processes

02 Scale problems of soil hydrological measuring techniques

Convener: Huwe, B.
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SOIL MOISTURE MONITORING AT FIELD SCALE USING AUTOMATIC CAPACITANCE PROBES

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In this paper we analyse how the soil moisture at field scale can be inferred from a capacitance probe (CP). It makes very local measurements (~cm^3), but can't be calibrated at this local scale . We propose to calibrate the CP by drawing up a direct relationship between the field average soil moisture and the CP measurements. Statistical consequences of such a calibration procedure are then discussed. Three experiments of several months were carried out on tilled fields to evaluate the CP against gravimetric measurements. Results show that the calibration relationships differ significantly from one CP to another. Once calibrated, the CP provides accurate soil moisture measurements with the exception of infiltration periods, during which preferential flows alter dramatically the CP representativity in comparison with the field. If several sites are implemented on a same field, measurements taken at the best site appear to be a good estimator of q_f. Soil water storage (Ws) is well estimated by combining 4 to 7 CP in spite of the error induced by each CP. Moreover, the temporal variations in Ws are well measured over several days periods or between two days.

VARIOGRAPHY OF WATER CHARACTERISTIC FUNCTIONS AT THE 10 m SCALE IN A CONIFEROUS FOREST: COMPARISON OF LABORATORY AND FIELD METHODS

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To predict the acidification of an aquifer at a forested location with sandy soils the spatial and temporal dynamics of solute fluxes must be modelled. A simulation of heterogeneous water and solute fluxes is based on a detailed knowledge of the spatial structure of soil physical material properties. The small scale heterogeneity of water retention at our research site is analyzed using two different approaches of data aquisition. From a 10 m long and 1.5 m deep transect 350 soil cores were taken. The water characteristic functions of these samples were determined in the laboratory using 6 different suction heads. Along a second 10 m long transect located nearby at 54 positions pairs of tensiometers and TDR probes were installed at 3 different depths. The water contents and matric potentials were used to derive field measured water characteristic functions for each position. The water characteristic functions of both data sets are scaled seperately and the scaling factors are subsequently analyzed with geostatistical methods to infer the spatial variography.
Results of the laboratory and field method are compared and interpreted.

SIMPLE TIME SERIES MODELS TO DESCRIBE NONLINEAR RUNOFF GENERATION

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The initial conditions of the groundwater level and the soil moisture deficit determine the extent of the nonlinear properties of the runoff generation. To quantify the effects of groundwater depth and soil moisture content on runoff generation, we conducted a controlled irrigation experiment. The subjects of this study were two sloped soil plots which were separated from their direct environment by trenches. The first plot has a muck humus topsoil and a fully reduced clayey subsoil. The second plot has a needle-covered mor humus topsoil and a partly reduced and well structured clayey subsoil. On these plots we applied a series of water pulses in a design that mimicked different combinations of initial soil moisture and groundwater conditions. For this purpose we used a mobile sprinkling device that was constructed to apply large pulses of water to the sloped plots. The runoff was collected in 3 depth layers and measured by means of tipping buckets connected to a datalogging system. Simultaneously, soil moisture content, soil water potential and depth of the groundwater table were monitored. The recorded hydrographs were modelled by means of simple discrete linear transfer functions. Subsequently, we looked for correlations of the parameters of the transfer functions with measured soil moisture contents and depth of the groundwater table.

DETERMINATION OF GRID SIZE FOR DIGITAL TERRAIN MODELS IN SOIL MOISTURE MODELLING

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A basic problem of combined analyses of digital terrain models (DTMs) and soil data is determination of competent grid size of DTMs (w), that is, a DTM grid size best suited to modelling of relationships between topography and a soil property. In fact, one has to estimate typical sizes of relief elements that affect the soil property. We developed an experimental statistical approach for w determination. The approach is as follows: (a) derivation of a set of DTMs using a series of grid sizes, (b) correlation analysis of soil data with a set of DTMs, (c) graphical representation of correlation coefficients estimated versus grid sizes, (d) analysis of a plot obtained to determine its portions marked by smooth and relatively small variations in values of correlation coefficients. These portions relate to zones of w. We demonstrate an application of the approach developed to an analysis of the influence of topography on spatial distribution of surficial soil moisture on the south of Moscow Region, Russia. As DTMs we use data on slope gradient, plan, profile and mean landsurface curvatures.

PROCESS TOMOGRAPHY IN THE HYDROLOGICAL SCIENCES: FIRST RESULTS

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In soil physics and process engineering laboratory experiments concerned with hydraulic transport phenomena of liquid and gaseous substances are typically carried out in column configurations (reactors). These phenomena are characterized by measurements like flow rate and/or volumetric water content at one or several points. However, the information contained in such measurements is minimal and in certain situations, e.g. multi-phase flow, a measurement technique discriminating different phases does not exist. We investigate the applicability of microwave tomography for the two-dimensional imaging of the interior of columns (reactors). This methodology employs the transmission of electromagnetic signals through a column setup. Like in medical tomography a circular geometrical arrangement will be used for the data aquisition, which is one-dimensional, namely transmitted voltage versus time. Therefore measurements must be taken from different azimuthal directions. The reconstruction of the spatial distribution of the dielectric properties, which can be related to quantities of interest via calibration functions, is an *inverse* and additionally *ill-posed* problem whose solution is based on regularization techniques.

INSPECTION OF THE FLOW PATTERNS AND PARAMETER ESTIMATION OF CAPILLARY BARRIER SYSTEMS AT DIFFERENT SCALES

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Capillary barriers, consisting of fine-over-coarse sand layers underneath a top soil, are currently under investigation as an alternative cover system for landfills and waste heaps. Due to capillary forces at the textural contrast infiltrating soil moisture builds up above the interface and flows downdip laterally. In order to inspect the relevant flow patterns in such a heterogeneous system and to develop applicable design criteria, experiments were conducted at different scales: core samples, in a 8 m long flume and on 40 x 10 x 3 m lysimeters under field conditions. In the field site the dynamics of soil moisture movement was recorded at the tensiometer/TDR scale; surface runoff and subsurface vertical and lateral fluxes were measured at large scale simultaneously.

For design purposes effective hydraulic properties of the layers have to be determined to predict the fluxes with suffiicient accuracy. Numerical simulations based on (1) parameter estimation on soil core samples and (2) calibration of hydraulic properties are compared with large scale observations on the test sites. A reliable prediction of the observed flow patterns was only achieved when the relevant flow process was consistent with the scale on which the hydraulic properties were determined.

A non-invasive approach for measurements of near-surface water content

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Surface water content (w) is a key parameter in hydrological modeling as the soil surface represents the boundary between the soil system and the atmosphere. A non-invasive approach for measurements of near-surface water content and bulk electrical conductivity (EC) using time domain reflectometry (TDR) is presented. In this approach, an ordinary three-rod TDR probe is used together with a PVC surface block which surrounded half the measurement volume. Theoretical and experimental results show that an analytical solution of the apparent dielectric constant (K) and EC of the soil is possible. Thus, the suggested technique does not require separate calibration of the w-K relationship. The variability of the measurements was shown to be slightly higher than using the traditional approach. The spatial sensitivity of the suggested technique was also investigated. It was shown that using a three-rod TDR probe with a rod spacing of 0.05 m allows the w and EC to be measured in the uppermost two centimeters of the soil. The fact that ordinary three-rod probes can be used and that the surface block is simple and cheap to manufacture, makes it possible that any TDR system can be upgraded to near-surface measurements.

INFILTRATION EXPERIMENTS AND SCALE EFFECTS

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A data set of 31 infiltration experiments with infiltration excess overland flow is used to study the infiltration in a natural soil. The experiments are performed on different plots (1 m^2) along a 90 m grass strip using a sprinkler infiltrometer. The experiments show a strong event-dependence: an increase of the rainfall intensity leads to an almost proportional increase of the infiltration rate, and to a small increase of the overland flow rate. It may be supposed that this phenomenon is a result of the small scale heterogeneity: larger rainfall rates tend to activate more effective flow paths.

A process oriented, two-domain infiltration model for simulating the flow process in the matrix, the macropore system and the interaction is used to simulate the experiments. The representation of the plots as horizontally homogeneous areas does not yield the observed event-dependence. Assuming that soil matrix or macropore characteristics follow a probability distribution greatly increases the agreement between observation and simulation. Simulations with different model assumptions and parameterizations indicate that the infiltration behavior of the plots is strongly influenced by the heterogeneity of the macropore system. This small scale variability leads to the observed event-dependence and to a fundamentally different infiltration behavior at the point scale and the plot scale. A consequence is that infiltration experiments can be used for parameterization of infiltration models only if this scale effect is considered.

Abstract

The problem of the scale dependency of transport processes is traced back to the action of the variability of parameters on the microscale, e.g. the hydraulic conductivity or the adsorption constant of transport processes. Since the variability of these parameters is not introduced explicitly into the transport equations, it is hidden in the effective transport parameters the solute transport is described with usually. Regarding the variability of the parameters explicitly in the transport equation it can be shown quantitatively how the fluctuations of the parameters bring about the so called scale effect on large scales. For this purpose methods from perturbation theorie and renormalization theory are used, and it is shown with 2 examples, how the variability of the adsorption constant affects the transport on large scales. Herewith the consequences of a change of scales are presented in an exemplary fashion.

ASSESSMENT OF MORPHOLOGICAL PROPERTIES BASED ON CALCULATION OF INTERNAL AND EXTERNAL HETEROGENEITY

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Lack of knowledge exists concerning the spatial range of validity of functional soil properties in water and solute transport studies. First quasihomogeneous morphological basic units have to be identified before they can be related to functional properties. Several methods using upscaling and downscaling procedures in connection with narrow spaced, grid related investigations are already known. In this study volume or area elements, based on pixel data sets, were aggregated stepwise within the considered field or object (soil core, profile, field scale). Then for subunits of different size the so-called internal and external heterogenity were calculated. It concerns standard deviation of volume or area elements within the field or object (external heterogeneity) and standard deviation of pixels within volume or area elements (internal heterogeneity). Both parameters describe the morphology of structures in an inverse manner; they characterize the narrow spaced heterogeneity, the spatial distribution and size distribution of quasihomogeneous soil structural elements. Combined with geostatistical approaches the calculated internal and external heterogeneity provides information for the identification of morphological basic units.

THE ACCURACY OF WATER CONTENT MEASUREMENTS WITH GROUND-PENETRATING RADAR: A MODEL EXPERIMENT

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The Nyquist theorem relates the minimum sampling frequency to the smallest variation within the sample. Strict application of this theorem to water content measurements on a field scale would therefore result either in prohibitively large sample numbers due to small probing volumes or in less samples, but with larger sample volume. Upscaling of small-scale measurements done by TDR, tensiometry, or gravimetry, will therefore inevitably result in additional noise.

Recently, a modification of the ground-penetrating radar (GPR) technique has shown that the soil water content can be determined non-destructively and rapidly in large-scale field surveys. The sampling volume of the method is about 1 to 2 m^3 with a spatial resolution of a few meters. The Nyquist requirement is therefore fullfilled. Because the accuracy of a model depends on the accuracy of the data used in the development of that model, we designed a field model experiment. In a sand-filled pit the accuracy, the dependence of the influence depth of the ground wave on the frequency and the sampling volume were ckecked at different water levels. Comparison with the gravimetric method and with TDR shows good agreement.

DAILY OSCILLATIONS IN SOIL TENSIOMETRY: A FIELD EXPERIENCE

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Continuous recording of soil water tensiometry frequently shows the occurrence of daily oscillations. Instrumental rather than actual soil behaviour causes have been usually claimed for these irregularities. A three-site experience in a mountain environment with simultaneous recording of weather, soil temperatures and forest transpiration demonstrated several types of oscillations. The aim of this work is to discuss the relationships between these oscillations and the other variables recorded, as well as to analyse the role of other factors, like rainfall events and the maintenance of the instruments.

CHARACTERIZATION OF SOIL HIDRAULIC PROPERTIES OF A FIELD UNIT USING DIFFERENT METHODS

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The soil hydraulic conductivity of an agricultural terrace with silt-loam soils was intensively measured in order to parametrize hydrological models within the VAHMPIRE project. The methods used include double ring permeameter, Guelph permeameter, as well as constant-head permeameter tests performed in the laboratory with disturbed samples.
The use of these direct methods was complemented with geophysical methods like ground penetrating radar, seismic refraction and electrical soundings, that provided information on geometry and stratigraphy of the soils.
The electrical method that is commonly used to determine rock formations and depths in the ground, provide electrical resistivity values that can be related to hydraulic conductivities. Here the method has been applied to verify if the hydraulic conductivities obtained can be compared with field measurements and provide a method for upscaling point measurements

HSA7 Open session on hydrology and living communities

Convener: O'Kane, J.P.

3D LIMNOLOGICAL MODELLING: METHODOLOGY AND TEST CASE

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A 3D ecological model is presented here . The hydrodynamic model uses the hydrostatic assumption in the vertical to solve the 3D Navier-stoke equation. A full ecological model has been added to this hydrodynamic model. It includes several phytoplankton and zooplankton species, nutrients (phophorus, nitrogen and silica), dissolved oxygen and organic carbon. A special attention was given to the sediment transport. In the water column, several size classes of particles are modelled. Aggregation, diferential settling, resuspension and deposition are the main processes that affect the size distribution. A two layered sediment model is also included. Deposition, resuspension, consolidation and erosion are the major processes described in the model that affect the granulometry and the sediment layers thickness. The model was applied on the lake Burragorang (near Sydney, Australia) for two particular scenarios. The first one was the study of the impact of a strong wind event. The second was the study of a flood.

HYPORHEIC ZONE RESIDENCE TIMES IN FIRST-ORDER STREAMS

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The hyporheic zone, or stream - aquifer interface, is a region of mixing between surface water and ground water and often a region of intense biogeochemical activity. One factor determining the nature and extent of these biogeochemical reactions is the amount of time dissolved species reside in the hyporheic zone. This time, represented by a mean/median residence time, or better still, a residence time distribution (RTD), can be calculated using tracer data and an appropriate model. We use a simple compartment model, calibrated with bromide tracer data, to simulate the stream - hyporheic zone system and calculate hyporheic zone mean/median residence times and RTDs for reaches along two first-order streams: the Rio Calaveras (RC) and Gallina Creek (GC) in New Mexico, USA. Each reach is approximately 2500m above mean sea level. The RC flows through an alluvial valley derived from a parent lithology of welded tuff. The GC is in an alluvial valley derived from granite and gneiss; its mean alluvial hydraulic conductivity is roughly four times that of the RC alluvium (0.004 versus 0.001 cm/s). The degree of stream - ground water exchange at GC is greater than that at RC, a fact reflected in the range of mean/median residence times, which range from a few hours to a few weeks, with mean and median residence times greater at RC. Our simple model provides results consistent with the OTIS numerical model.

HURST'S LAW IN THE VARIATIONS OF THE KASPIAN SEA LEVEL AND THE ESTIMATING THE RANGES OF THIS VARIATIONS

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Historical series of the Caspian sea level records for 105 years have been used to determine the dependence of the range of these variations upon the lag S. The Hurst approach and the variogram method have been applied. It has been shown that the rescaled range of the variations of the Caspian sea level is proportional to S^H with H is nearly 0.65 and these variations can be considered as a stohastic fractal. To explain Hurst's effect stochastic effect of the Caspian sea level series have been constracted (ARIMA(1,0,1), nonstationary water balance models with a feedback and without a feedback). The influence of series lengths and nonstationarity on the value of H has been investigated. It has been established that the value H changes with increasing the series length slowly and the value H can be considered as a constant for practical estimations (for periods of 100-200 years).

HSCI-04 - SOURCES AND TRANSFER OF WATER AND SEDIMENT IN MEDITERRANEAN RIVER BASINS

We are in charge of the special hydrological symposium on Mediterranean river basins for the 1998 European Geophysical Society (EGS) General Assembly in Nice during 20-24 April, and we invite all interested scientists to present their research on this topic.The main aim of the symposium is to contribute to the research of water and sediment budgets in river systems and will focus on areas under Mediterranean climatic conditions world wide. We welcome contributions on water and sediment sources, both natural and anthropic (agriculture, forestry, urbanization, etc.), and on their transfer to the river system by the hillsope and stream network. Oral and poster contributions are invited. Deadline for submission, by e.mail to the EGS Office and copies to the convenors, is 15 January. It is expected that a selection of papers will be punblished in a special issue of a Hydrology and/or Earth Science Journal. Interested researchers are iinvited to contact the session organizers requesting EGS regitration and abstract forms.

HSA8 Hydrology and chemical processes - restoration of aquifers: natural and artificial attenuation

01 Natural attenuation and intrinsic bioremediation: field studies

Convener: Grathwohl, P.
Co-Convener: Totsche, K.-U.

EVALUATION OF NATURAL BIOATTENUATION AT THE MACRO- AND MICROSCOPIC LEVEL: FIELD IMPLEMENTATION OF NOVEL MONITORING METHODS

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The demonstration of natural attenuation in the field requires extensive characterization of the subsurface geophysical and biogeochemical conditions to provide information on *in situ* microbial activities and potential for contaminant biodegradation. A number of geophysical (GPR, Sonar), geochemical (H_2 measurements) and microbiological (phylogenetic profiling) monitoring techniques were applied to evaluate the bioremediation potential at a groundwater-surface water interface with Lake Michigan, and the capillary fringe zone below a fire training area, both contaminated with chlorinated solvents. The inherent differences in resolution afforded by these techniques allow for different levels of inquiry. The geophysical techniques aided in the resolution of plume migration and emergence, and reflected ionic contributions from respiratory processes. The dissolved hydrogen concentration allowed for a temporal and spatial characterization of dominant microbial electron accepting processes along cross-sections of the plumes. The genetic techniques enabled the temporal resolution of the microbial community structure, which is indicative of microbial biodegradative activities which can be expected to act on the contaminants. A combination of these techniques with activity measurements in the laboratory and contaminant distributions within the plume allowed for an evaluation of the *in situ* natural bioattenuation potential at both sites.

INVESTIGATION INTO THE NATURAL ATTENUATION OF A DISSOLVED CREOSOTE PLUME

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A methodology was developed and applied to investigate the natural attenuation possibilities, especially anaerobic bio-degradation, of a dissolved creosote plume at a wood preserving facility located next to a major river. Multiple lines of evidence were pursued to determine which natural attenuation processes are important at the site. These studies included: (1) literature searches for lab and field studies done under similar conditions to the field site, (2) site investigation work, including the novel use of a drive point profiler to obtain highly detailed 2D cross sections through the plume both inland and underneath the river, (3) lab microcosm and sorption experiments using site sediment and groundwater samples, (4) in-situ microcosms, and (5) reactive transport computer modelling.

Results of the profiling show that a large anaerobic plume, comprised mainly of naphthalene, is leaving the site and is discharging into the river 50 - 90 m from the shore. The field evidence (contaminant ratios, modelling results) indicates that considerable mass loss of naphthalene, above and beyond that which can be easily explained by dispersion and sorption alone, occurs along the flowpath before the plume enters the river. The initial results of the lab and in-situ microcosm experiments show no evidence of anaerobic naphthalene degradation.

In spite of these initial microcosm results, anaerobic biodegradation of naphthalene is still considered a significant attenuation mechanism at this site.

EFFECT OF THE NON LINEAR SORPTION OF POLYCYCLIC AROMATIC HYDROCARBONS ON THEIR TRANSPORT PROPERTIES IN ORGANIC SOILS

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The present work takes place in the context of a global study on environmental risk assessment for PAH contaminated soils. One of its objective is the determination of soil sorption parameters of two pure PAHs (naphtalene and phenanthrene) during their transport by water. It is well known that sorption is mainly controlled by soil organic matter (content, polarity, origin etc.). Continuous flow laboratory column experiments have been performed with three different porous media: a sand, a natural organic soil and a "model" soil (sand impregnated with a heavy satured hydrocarbon as organic matter) representing a NAPL polluted soil. Sorption isotherms of both PAHs were determined thanks to the breakthrough curves. An important result is sorption non-linearity of both pollutants on the organic soil: sorption can be described by a Langmuir isotherm, while most literature review provides linear isotherms whatever soil type. Non-linearity is confirmed by breakthrough curve analysis. Another result is the different behaviour of naphtalene following soil organic matter composition: on the natural organic soil, isotherms are Langmuir type, as on the model soil, isotherms are Freundlich type ($q = KC^n$ with n>1). The importance of the non linearity on the biodisponibility of PAHs is shown by using a transport model coupling adsorption and 1D-dispersive-advective flow.

INTRINSIC BIOREMEDIATION OF VIRGIN NAPHTA IMPACTED SITE

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Intrinsic Bioremediation of dissolved petroleum hydrocarbons released from a virgin naphta contaminated site has been evaluated in a storage tank facility located in the Northern Italy, where approximately 300 m^3 of virgin naphta spilled out.
A dual pump extraction system (installed in three pumping wells) allowed the recovery of the floating phase, however the hydraulic barrier capture zone did not reduce the dissolved plume expansion.
This study verifies the capacity of the phreatic aquifer to reduce the dissolved phase concentration below the regulatory standards monitored in each point of compliance installed close to the property boundary.
A site characterisation has been carried out in order to achieve complete knowledge of the site-specific geologic and hydrogeologic data required to define a conceptual understanding of groundwater flow, plume location, plume direction, contaminant concentration and attenuation over time and distance.
Microbial enumerations provided evidence that the microorganism hydrocarbons degraders were present.
Shallow monitoring wells were installed along the groundwater flow pathways and were sampled for intrinsic remediation parameters. The monitoring activities have been carried out quarterly.
The results indicate that the groundwater contamination is attenuated to accetable standards within 150 m from the source area, and that the plume is stable.

NATURAL ATTENUATION OF LANDFILL LEACHATE PLUMES ?

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Evidence of natural attenuation at two Danish landfills is presented and discussed in relation to the possible introduction of natural attenuation as a remediation technology for leachate plumes. The following issues are in particular of importance in this context:

- The fact that landfills often are very large, having locally very heterogeneous hydrogeology and waste composition, may create more plumes of different characteristics from the same site. This complicates the detailed plume mapping needed to document attenuation of key leachate components in the aquifer.
- The leachate contains different groups of contaminants (dissolved organic matter, organic chemicals, heavy metals and inorganic ions), which all must be assessed. Organic chemicals and maybe ammonia seem most critical in leachate plumes.
- The redox zones of the leachate plumes are important for the degradation of the organic chemicals. Thus, also determination of the redox conditions must be performed. By plume mapping, mass removal has been demonstrated at two landfills, but confirmation of the apparent degradation has not always been obtained by controlled experiments in the laboratory or by field experiments. For some of the organic chemicals half-lives of years have been observed; a fact that complicates the documentation of mass removal. In particular for benzene inconclusive results have been found.

IN-SITU CHARACTERIZATION OF NAPL AQUIFER CONTAMINATION BY PARTITIONING AND INTERFACIAL TRACERS

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Hydrophobic organic contaminants released from non-aqueous phase liquids (NAPL) impose a serious risk on groundwater quality. NAPL can exist as coherent "pools" or residual phase ("blobs") within the aquifer. Depending on the NAPL volume the time scale of contaminant emission may be centuries or longer. The concentration in groundwater depends on NAPL volume and interfacial area between NAPL and water. The knowledge of these is essential for site characterization, risk assessment and planning in-situ aquifer remediation techniques. This paper describes characterization for NAPLs using partitioning (volume) and interfacial tracers. Laboratory studies (undisturbed soil columns, batch experiments) were conducted using coal tar contaminated material from a former manufactured gas plant site. Sulphur hexafluoride (SF_6) and different alcohols (substituted pentanols) have been tested as partitioning tracers. An anionic surfactant (ethoxylated alkyl sulfate) was used as the interfacial tracer. The alcohols have a low but significant octanol/water partition coefficient K_{ow}, which was found to be between 24 and 240 and a resulting NAPL/water partition coefficient between 1 and 22. The surfactant accumulates significantly at the NAPL/water interface. While these reactive tracers were not retarded by the natural aquifer material, they were retarded in the presence of NAPL with respect to the transport of a conservative tracer. The NAPL saturation was calculated from the retardation factor and the partition coefficients, which were measured independently in batch experiments.

NATURAL ATTENUATION PROCESSES IN A BTEX PLUME

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Within the framework of a current research program (funded by the German Research Foundation) natural attenuation processes of BTEX have been investigated in a Quaternary porous aquifer below a manufactured gas plant in Southwest Germany. The investigation site offers the opportunity not only to access the contribution of microbial reduction to the natural attenuation but to determine other multiple processes as well, including both aerobic and anaerobic milieu conditions. Seasonal and regional variations of the BTEX plume have been registered since 1996 by detailed hydrochemical monitoring and frequent soil gas investigations. On-site soil-gas surveying is applicable for the determination of the magnitude and lateral extent of VOC plumes. Taking into account that degradation of organic compounds results in O2 decrease and CO2 increase in the soil air, analysis of both parameters have been carried out on-site. Measured soil gas CO2-anomalies correspond quite well with the observed contamination pattern of the groundwater because the biodegradation of organic compounds causes an additional diffusional CO2-transport. Although soil-gas surveying is usually applicable to the most volatile organic compounds, at the test site only very low concentrations of VOC's have been detected in the soil gas above the contaminated groundwater. In order to understand the results of the field investigations, physical, chemical and microbial processes determining the VOC concentrations have been investigated in detail in lab scale.

BIODEGRADATION OF ORGANICS IN SOIL

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Abstract

Natural attenuation of organic pollutants in the environment is controlled mainly by two groups of parameters: (i) environmental characteristics (*e.g.* soil organic matter content and nature, availability of nutrients or oligo-elements or microbial activity) and (ii) chemical characteristics (*e.g.* hydrophobicity of the pollutant, structure etc.).
Slow biodegradation kinetics in soil relative to lab aqueous medium is explained by sorption and weaker bioavailability of hydrophobic organic xenobiotics and controlled mainly by the nature and quantity of soil organic matter.
Laboratory tests (organo-chlorinated molecule, pure bacterial strain of *Rhodanobacter*, 4 soil suspensions which organic matter has different polarities, 30 °C, nutrient broth added as co-substrate) shown that biodegradation kinetics for soil suspensions are **(a)** always lower than the one determined for the control (without soil) and **(b)** oppositely correlated to the concentration of sorbed chlorinated compounds.
In a second study, we have examined potential parameters describing environmental characteristics and chemical characteristics in order to elucidate the most important for predicting natural attenuation kinetics. We have constructed a data base from literature data (800 scientific papers were examined providing a subset of 75 publications with 26 soils and 55 compounds, given a total of 150 data). Under optimum or near optimum environmental conditions biodegradation rates appear to be controlled by molecular characteristics and under more extreme conditions biodegradation rates controlled by environmental characteristics.

INVESTIGATION OF NATURAL ATTENUATION OF ORGANIC GROUNDWATER CONTAMINANTS AT FIELD SCALE

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For the development and testing of techniques suitable for the investigation of subsurface contaminations, a test site is operated at a former coal gasification plant. Within the sand and gravel aquifer, NAPL pools, as well as a contaminant plume of several hundred meters length, consisting mainly of dissolved PAH and BTEX, are detected. For the investigation and evaluation of the natural attenuation of the contaminants, the processes of advection and hydrodynamic dispersion, sorption/diffusion and degradation have to be considered. The advection and contaminant dilution due to hydrodynamic dispersion is evaluated using data from detailed tracer experiments. The sorption/diffusion of the contaminants is estimated based on the lithological composition of the aquifer material and apparent diffusion coefficients specific to the contaminants for each lithocomponent. Contaminant degradation, a prerequisite for the stationarity of a contaminant plume, is quantified by comparing the measured concentration distribution and contaminant mass flux within the plume with transport model predictions considering only advection, dispersion and sorption/diffusion. The paper presents the conceptual approach, the measurement techniques used, some first measurement results, as well as model simulations.

PARTITION OF AROMATIC HYDROCARBONS FROM OXYGENATED GASOLINES INTO WATER

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Groundwater contamination by nonaqueous phase liquids such as organic solvents and petroleum hydrocarbons frequently occurs as a result of the leakage during transportation, storage and distribution. The leak or spill of oxygenated gasoline will induce a solvent flushing effect in the contaminated soil due to the high solubility of oxygenated compounds in water. The oxygenated compounds will furthermore reduce the retardation factor in groundwater transport of aromatic hydrocarbons (BTEX), and cause these compounds to coelute at an earlier time in the contaminant sites. This work focuses on the experimental measurement of the enhanced solubility of aromatic hydrocarbons with increasing percent ethanol. Specifically, the phase redistribution of contaminants in a sandy soil upon the addition of oxygenated gasoline was studied in packed columns to simulate the spill fuel in subsurface environment. The soil samples were collected in São Paulo States, Brazil where a gasoline pipeline of 400 km length crosses the Botucatu Formation. 90% of the water which the population and the industry consume, comes from this aquifer. From the perspective of human health effects, the volatile aromatics hydrocarbons fraction of gasoline products is of concern because benzene is classified as carcinogen. Results show that the solute solubility of the compounds increased curvilinearly with an increase in percent ethanol.

INTRINSIC BIOREMEDIATION OF A PETROLEUM HYDROCARBON-CONTAMINATED AQUIFER: ASSESSMENT BY STABLE CARBON AND SULFUR ISOTOPES

Patrick Höhener, Christof Bolliger, Daniel Hunkeler, and Josef Zeyer

This paper discusses the use of stable isotopes to assess the microbial PHC mineralization processes in a heating oil-contaminated aquifer in Switzerland. A spill of an unknown quantity of heating oil caused the formation of an oil body of 85 m length and ~25 m width at a depth of 3 m below ground. The direction of the ground water transport at this site was verified by a natural gradient tracer experiment. Chemical analysis of ground water samples from monitoring wells along and perpendicular to flow revealed that dissolved hydrocarbons were present in the ground water below the floating oil body. Oxidants such as O_2, NO_3^- and SO_4^{-2} were depleted, whereas reduced species such as Fe^{2+}, Mn^{2+}, H_2S and CH_4, as well as dissolved inorganic carbon (DIC) and Ca^{2+} were elevated. Stable carbon isotope ratios ($\partial^{13}C$) in DIC were more negative in the ground water below the oil compared to ground water upstream Using stable carbon isotope balances, it was calculated that 88 % of the DIC produced at this site originated from microbial PHC mineralization. Furthermore, stable sulfur isotope ratios ($\partial^{34}S$) in sulfate were more positive in groundwater below the oil compared to upstream, suggesting that increased fractionation due to microbial sulfate reduction is occurring in the contaminated zone.

FIELD EVALUATION OF PHYTOREMEDIATION STRATEGIES IN TPH DEGRADATION

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Laboratory studies have shown phytoremediation to be a feasible method for remediating surface soils contaminated with petroleum products. Evaluation of this technology in the field is made difficult because of spatial variability issues. In this study, total petroleum hydrocarbon (TPH) degradation was monitored over a field site with three vegetative treatments and one control plot undergoing natural attenuation. Within each treatment, TPH concentrations were monitored at twenty locations over time to study the phytoremediation potential of the different vegetative treatments. For comparing the performance of different treatments and the control site in a quantitative manner, first order kinetics were assumed to be applicable. The degradation rates were treated as spatial random variables, and the overall behavior of these rates were computed based on concentration measurements. It was observed that these degradation rates are good indicators of performance in the field, and can provide quantifiable answers using simple hypothesis tests. These results will be discussed, along with experimental evidence that indicates how plants perform in the field for TPH degradation.

ATTENUATION BY NATURAL AND ENHANCED SORPTION OF HOCS IN A LANDFILL LEACHATE

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Natural and enhanced attenuation of the Norman landfill plume are being evaluated to protect the adjacent Canadian River. This research focuses on the role of sorption in the attenuation process. Canadian river alluvium has been used as the natural sorbent material and alkylbenzenes, chlorobenzenes, and polycyclic aromatic hydrocarbons have been tested for their sorption properties under both equilibrium and nonequilibrium conditions. Experimental parameters such as equilibration time, grain size, organic content, pore water velocity, etc. were varied in order to determine their effect on sorption parameters. The data have been interpreted using existing models and the effect of experimental variables was quantified. Enhanced attenuation of phenanthrene has also been evaluated with activated carbon as an additive. This presentation will discuss important factors that affect the natural and enhanced sorption, and thus also the bioavailability, of these different categories of aromatic hydrocarbons.

ROLE OF GEOPHYSICS IN AQUIFER VULNERABILITY ASSESMENT

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Hydrogeophysical exploration means exploration of shallow subsurface geological formations of insignificant thickness, which requires outsdanding accuracy of obtained results. Within hydrogeological exploration, geophysical methods have a significant role in solving following problems: defining aquifer geometry and structural properties as well as relevant indications on a hanging-wall permeability characteristics and aquifer hydrodinamic parameters; monitoring aquifer contamination by mineral and organic deposits; exploration of velocity transfer for wet front and pollutant within, etc.

As a case history, an area of Djerdap reservoir on the Danube river (Serbia, Yugoslavia) is presented. Namely, complex geophysical exploration (seismics, well-logging, electric and electromagnetic methods) has been done in order to prevent and moderate a harmful influence of the performed reservoir on the environment. In that sense, a hydrogeophysical investigation was useful in delineation of the aquifer, obtainment appropriate parameters, as well as mapping the aquifer vulnerability. Then, land-use planning and development of strategy for groundwater protection and management was possible.

AN INVESTIGATION OF THE BIODEGRADATION OF PHENOLICS WITHIN THE VADOSE ZONE

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A smokeless fuel plant operated at a site on the triassic sandstone aquifer (an important water resource), with a vadose zone 20m in depth. During this time there was a release of wash water into the ground, containing high concentrations of ammonium and phenol, cresols and xylenols. Today no traces of the organics have been found in the groundwater while the ammonium remains. This study of natural attenuation in the vadose zone uses intact cores from the site, in a novel system to control the saturation of the cores contained in the continuous flow system. The rate of degradation of the phenolics is studied under different environmental conditions to allow the rate of natural attenuation within the field to be predicted and to identify the limiting factors, to aid in the design of vadose remediation schemes. Results show that there is a very short lag period prior to the onset of degradation (frequently less than 24 hours) followed by an increasing degradation rate with mixed phenol concentrations up to 60ppm. All of the compounds investigated to date have been degradable and there is no evidence of sequential or co-metabolism. The system is capable of operating for sustained periods, and to date there is no evidence for a drop in the degradation rate within the core.

IN SITU BIOREMEDIATION IN CASE STUDIES, NL

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1. Aliphatic hydrocarbons are eliminated by the in situ microflora of the soil. Additionally, infiltration and injection devices for nutrients, enhanced natural microculture additives, emulgators and oxygen feed the cultures in the deeper parts of the subsurface. Remediation time varies between 1 to 3 years. Groundwater is pumped and treated in 2 to 3 small mobile containers, equipped with bio- and compostfilters, air strippers,soil gas ventilation systems and sun collectors for heating. A petrol station with 20,000 mg/kg in soil and 60,000 μg/l in groundwater was reduced to < 2 μg/l.
2. High volatile hydrocarbons are biologically degradable by high pressure air injection. Only the upper centimeters of the aquifer are stripped and biologically treated. Oxygen is added in large quantities to accelerate biological activity. A gasoline contamination in loamy sands,another within a contaminant cocktail of 20 solution agents in heavy loess loams decreased from $> 5,000$ mg/kg to < 100 mg/kg within 22 days.
3. Polycyclic aromatic hydrocarbons with up to three benzene rings are biologically degradable. Certain mould fungi are capable of penetrating the surface of higher number PAH's in symbiotic relation with PAH degrading bacteria. A second mechanism is provided by a medium which contains enzymes and certain additives which "soften" the surface of PAH molecules. A decline from 680 mg/kg to less than 10 mg/kg (200 days) was observed.

NATURAL ATTENUATION OF AROMATIC HYDROCARBON AND HALOALIPHATIC COMPOUNDS IN GROUND WATER

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Contaminant plumes in which aromatic hydrocarbon compounds and chlorinated solvents often commingle. Haloaliphatic and aromatic hydrocarbon compounds can be naturally attenuated by biotic or abiotic transformations depending on conditions and structure. Transformations can lead to a range of products and are dependent on compound structure and environmental conditions. Anaerobic conditions favor the attenuation of both compound classes. Some haloaliphatics are utilized as the primary substrate or as the electron acceptor, or are transformed cometabolically. Insight into the mechanism of biotic dehalogenation has been obtained by studying reactions of reduced cobalamin with chlorinated C-1 and C-2 compounds. A substantial body of evidence shows that BTEX compounds can be oxidized anaerobically by different electron acceptors. Recent pure culture studies under nitrate- and sulfate-reducing conditions indicate anaerobic toluene oxidation is initiated by addition of toluene to fumarate to form benzylsuccinate (BS). BS and related metabolites have been found in the field at a study site where toluene and other alkylbenzenes were released. Laboratory studies and field evidence indicate that natural attenuation of BTEX and haloaliphatic compounds in commingled plumes could be linked.

TEMPORAL AND SPATIAL TRENDS WITH BIOGEOCHEMISTRY AT A GROUNDWATER-SURFACE WATER INTERFACE: IMPLICATIONS FOR MICROBIAL BIOREMEDIATION PROCESSES

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The biogeochemical effects of a turbullent surface water on a contaminated anaerobic groundwater at the groundwater / surface water interface (GSI) were evaluated using spatially discretized multilevel arrays, and interpreted in light of natural bioattenuation mechanisms. Groundwater samples, collected during a five-month evaluation period with increasing storm activity, were evaluated to determine the effect of lake activity on the degree of oxidation and contaminant distribution within the plume. Our analyses indicate that concentrations of methane and 1-chloroethene decreased as the groundwater became increasingly oxidized along the GSI in shallow sample points impacted by infiltration of oxygenated lake water. cis-1,2-Dichloroethene remained unchanged or slightly increased at the same locations indicating that the decrease in methane and 1-chloroethene was not due to physical effects. Moreover, negative correlations of 1-chloroethene and methane data with oxygen suggest that 1-chloroethene is co-oxidized by methane oxidizing bacteria in the shallow zone of the plume. Contrary to oxidative processes in the shallow zone, reductive dechlorination of contaminants remained the predominant biotransformation process in the deep zones of the GSI. This study is the first to evaluate the effects of seasonal changes on a chlorinated ethene contaminated plume at the GSI in spatial and temporal detail.

TRACING THE TRANSFORMATION OF POLYCYCLIC AROMATIC HYDROCARBONS (PAH) DURING MICROBIAL DEGRADATION WITH STABLE ISOTOPE LABELLED SUBSTANCES IN SOILS.

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We have applied 13C-labelled PAH to study the flux and transformation of organic xenobiotics in soils on a bulk and molecular level. The 13C-label is used to trace (i) the degradation of the pollutants, (ii) the evolution of CO2 and (iii) the formation of bound residues in the microbial soil system. The carbon budgets based on the 13C-label are calculated and elucidate the response of the microbial system to the pollutants load. Moreover, the 13C-label is used to identify metabolic products of the former PAH within the complex matrix of natural soil born compounds and therefore allows structural studies of bound residues. The complete metabolic transformation of the 13C-label into natural compounds can be recognised on a molecular level applying IRM-GC-MS. The incorporation of the 13C-label into amino acids proves that the microbial community can use part of the xenobiotic carbon for its biomass reproduction. The contribution highlights the intrinsic properties of the microbial system to transform PAH in soils. Moreover, the advantage of 13C- labelled tracers compared to classical radiotracers is discussed.

CHARACTERIZATION OF PREDOMINANT REDUCTANTS IN AN ANAEROBIC AQUIFER BY REACTIVE PROBE COMPOUNDS

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The processes controlling the reductive transformation of contaminants in a biogeochemically heterogeneous anaerobic aquifer were inferred from the relative reactivity patterns of redox sensitive nitroaromatic probe compounds (NACs). Results of field experiments (continuous injection and *in situ* microcosms) were compared to the findings of laboratory batch and column experiments. Despite the presence of various potential reductants (e.g., dissolved H2S and Fe(II), [illegible] DOM, microorganisms) the patterns of relative reactivity of the probe compounds indicated that ferrous iron associated with Fe(III)(hydr)oxide surfaces was the dominant reductant throughout the entire anaerobic part of the aquifer. Our results suggest that Fe(II) associated with ferric iron minerals is a highly reactive reductant in anaerobic aquifers, which may also determine the fate of other classes of reducible contaminants such as halogenated solvents, azo compounds, sulfoxides, chromate, or arsenate.

MONITORING CONTAMINATED SITES - BALANCING TREATMENT EXPENSES AND THE COSTS FOR THOROUGH SITE CHARACTERISATION

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A Successful sanitation of contaminated sites requires thorough understanding of the transformation and transfer processes in soils and aquifers. Two different remediation strategies have made their way for practical applications: One favours high investments in monitoring and screening programs to thoroughly understand the governing processes and properties, while the other prefers putting to practice rapid actions to minimise health hazards. Based on the achieved understanding the former results in cost-effective treatment of the contamination plume while the latter has to assume worst-case scenarios to designate the extent of the contaminated area, which usually leads to expensive remediation actions.
However balancing costs and the investments in thorough characterisation of the contaminated site are important to achieve both, cost-effective and site specific remediation strategies and the acceptance by the owner and the authorizing agency. As an example case study we will report on a monitoring programme conducted at a waste disposal site contaminated with volatile compounds (VOC) and AOX. Dependend on two different sanitation strategies cost calculation and scientific demands for two monitoring programmes are delineated and discussed.

NATURAL ATTENUATION AND PLUME LENGTH OF ORGANIC CONTAMINANTS

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Natural attenuation (intrinsic bioremediation) has become an interesting alternative for the cleanup of contaminated sites. Contaminant plumes develop with time and may reach quasi-steady-state conditions. Hence, to rely on natural attenuation as a remediation technique, time and space downgradient of a site are required. In Europe, space is usually rare in the vicinity of contaminated sites. For example, at gaswork plants which are normally located within an urban area, potential receptors, such as municipal drinking water wells, are often very close to the contaminant source. In this study we present the results of a statistical analysis of the plume lengths of frequently in ground water occurring organic pollutants. The average plume length of volatile chlorinated hydrocarbons reaches 660 m in 75 % of the cases evaluated. Easily biodegradable organic compounds like the phenols and the BTEX (benzene, toluene, ethylbenzene and xylene) reach an average plume length of approximately 190 m and 140 m (75 % of the cases), respectively. Furthermore, the maximum plume lengths in 75 % of all evaluated cases did not exceed 2100 m, 600 m and 300 m for volatile chlorinated hydrocarbons, phenols and BTEX, respectively. These results are in good agreement with recently published data from California and Texas.

A NATURAL GRADIENT FIELD EXPERIMENT AT BORDEN - INVESTIGATION OF NATURAL ATTENUATION PROCESSES OF BTEX AND MTBE

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A natural gradient tracer test was performed in the shallow, aerobic sand aquifer at Canadian Forces Base Borden. A mixture of groundwater containing dissolved oxygenated gasoline was injected below the water table along with chloride as a conservative tracer. The migration of BTEX, MTBE and chloride was monitored in detail (3D) for sixteen months. The mass of BTEX compounds in the plume diminished significantly with time due to intrinsic aerobic biodegradation making this process the predominant natural attenuation mechanism. MTBE showed only a small decrease in mass over the sixteen-month period. A comprehensive groundwater sampling program eight years after injection was undertaken to define the mass of MTBE still present in the aquifer. The results suggest that biodegradation of MTBE had occurred over this eigth-year period, however, its relative importance with respect to dispersion/diffusion as a natural attenuation process is much less pronounced than for the BTEX compounds.

MODELLING THE TRANSIENT TRANSPORT OF NON LINEARLY INTERACTING DISSOLVED VOLATILE ORGANIC COMPOUNDS: EXPERIMENTAL VALIDATION BY COLUMN EXPERIMENTS.

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The present work takes place in the context of a global study on environmental risk assessment for VOC contaminated soils or ground waters. One of its objective is the determination of sorption parameters of two pure VOCs (benzene and toluene) during their transport in the saturated zone. The second is the development of a non linear transport model taking into account the kind of organic matter present in the soil.
Thus, laboratory column experiments were run with three porous media: a clayey and calcareous sand, natural soil-sand mixtures and a "model" soil (sand impregnated with heptamethylnonane as organic matter) representing a NAPL polluted soil. Benzene and toluene are not retained by the sand, but in the two other media, the two solutes exhibit different sorption behaviours: benzene sorption is linear on both organic media whereas toluene interaction with the model soil presents non-linearity effects (Freundlich isotherm $q = KC^n$ with $n>1$). A good knowledge of the solute uptake properties is required to achieve good transport predictions. The importance of the non linearity on the biodisponibility of VOCs is shown by using a transport model coupling adsorption and 1D dispersive advective flow.

HYDROCHEMISTRY IS MORE THAN TRANSPORT USING HYDROLOGY

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Until recently, concerns of ground water resource management still are focused on quantity issues (e.g. yield, velocity, drawdown). The most sophisticated solutions are achieved by hydrological modelling. Quality issues are getting attention because of increasing pollution. The accelerated degradation of natural attenuation zones causes breakthrough of nitrate, sulphate and micro pollutants and often cause drinking-water quality deterioration. To assess groundwater quality, a combination of hydrological modelling and hydrogeochemistry (incl. sediment/rock) is required. This provides the insight in the spatial distribution and controls of water quality; hydrological models alone are often ambiguous in the determination of flow pattern and ages. However, in practice it is impossible to sample an entire area. Strategic placement and sampling of multilevel wells should be used to verify the models. A case study of an aquifer system in the east of the Netherlands is presented. A cross-section comprising of 10 multilevel wells (approx. 1 km apart, mini screens at each meter to a depth of 60m) was sampled in 1989 and in 1996. The section starts in an ice-pushed ridge and runs into a cover sand plain. The groundwater flow is complex, with local and regional systems and multiple aquifers. Boundaries between local and regional groundwater flow systems, but also chemical variations caused by (hydro)geochemical changes in time within recharge areas are identified. Spatial changes in water chemistry could often be related to changes in land use (e.g. recharge water quality, cultivation from heather to pasture land), which varies in space and time. Because the latter, the development history of the region proved to be an essential factor determining groundwater quality.

ANTHRACENE TRANSPORT THROUGH AN UNSATURATED LAYERED SOIL COLUMN AS INFLUENCED BY RETARDATION AND INTRINSIC BIODEGRADATION

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Sorption, remobilization, and biodegradation govern the fate of polycyclic aromatic hydrocarbons (PAH) in soils. The coupling of these processes was studied in soil columns using a sandy forest soil and ^{13}C labeled Anthracene. The column was repacked in two layers with uncontaminated and artificially contaminated soil material and homogeneously irrigated for a period of 4 months at a flow rate of 250 ml p.d. Column effluent was analyzed for solution phase PAH concentrations and microbially released hydrogen carbonate. Evolved CO_2 was trapped using a carrier gas stream. Results show a week first flush of effluent PAH in agreement with the initially high release of soil borne dissolved organic matter. However, substantial breakthrough of Anthracene is observed after 350 porevolumes, only. Aqueous phase concentrations and post-experimentally determined solid phase concentrations will be discussed in the light of process coupling and compared to results from numerical simulations.

HSA8 Hydrology and chemical processes - restoration of aquifers: natural and artificial attenuation

02 New developments in in-situ treatment of subsurface contaminations

Convener: Rijnaarts, H.H.M.
Co-Convener: Bosma, T.N.

PRELIMINARY KINETIC STUDIES FOR AN IN SITU BIOREMEDIATION TREATMENT: TOLUENE REMOVAL FROM AN AQUIFER.

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A study for an in situ bioremediation of an aquifer contaminated for a long time by aromatic hydrocarbons, was carried out with particular attention to toluene, the most representative pollutant. During this work, an indigenous microbial consortium was found able to degrade toluene up to 180 mg/l concentration. The biodegradation tests were carried out in three different kinds of reactors (160, 1200 and 13000 ml volume) to evaluate microbial performance in toluene removal. Biodegradation occurs only in aerobic condition, with an adequate oxygen availability and nitrogen supply. Kinetic studies were performed and toluene removal reached 100% in about 50 days . Moreover, a toluene metabolites identification technique was set up. This investigation gave important information about toluene degrading microbial strains, on the basis of their metabolic pathways. In fact, it revealed the presence of *Pseudomonas* strains. In conclusion, the in situ aquifer bioremediation is a possible solution provided that oxygen and nitrogen are made available in the aquifer, e.g. by H_2O_2 injection or air sparging.

DISSOLUTION AND MOBILIZATION OF DISPERSED NAPL IN POROUS MEDIA BY SURFACTANT FLOODING

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The dissolution of dispersed NAPL (ganglia) by anionic surfactant flooding is experimentally investigated in glass pore network micromodels. The main parameters of the system (surfactant soncentration, c_s; sodium chloride concentration, c_{NACl}; Reynolds number, **Re**; Capillary number, **Ca**; viscosity ratio, **κ**) are changed systematically, whereas all other parameters (namely, type of surfactant, pore model characteristics, wettability, etc.) are kept constant. The rate of dissolution of a solitary ganlion (expressed by the mass transfer coefficient, k_L, or the dimensionless Sherwood number, **Sh**) is measured as a function of the dimensionless system parameters, as well as the dimensionless volume of the ganglion, V^*, the dimensionless interfacial area, A^*, and the ganglion position and orientation within the pore space. The mechanisms of volume reduction and all subsequent disconnections of the ganglion are continuously monitored, until smaller daughter ganglia are formed which are mobilized by the surfactant flood. It is found that the rate of ganglion dissolution is affected strongly by these mechanisms, whereas the formation of smaller ganglia enhances the rate of dissolution drastically, due to the mobilization of the smaller ganglia.

MERCURY REMOVAL FROM GROUNDWATER - AKTIVATED S-CHARCOAL ADSORPTION VERSUS Hg2+ REDUCTION BY TIN AND Hg(0) STRIPPING

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Mercury (Hg) contamination of groundwater is often attributed to pressuring sites where high amounts of HgCl2-solution used for timber impragnation were spilled into soils. In some cases were the conta-minated soil cannot be excavated or covered, groundwater contami-nation will last for decades or even centurys. Funnle and gate techno-logy has been considered as a possible method to prevent Hg plumes from dispersing. Hg in the groundwater of such sites mainly exists as Hg-chloride complexes or as Hg(0) up to 300 Ág/l, whereas only small amounts of Hg are bound to soluble organic complexes. In the present study sulfur-imprag-nated charcoal and Hg(0) stripping after Hg2+ reduction through tin filters were investigated to remove Hg from groundwater. Sulfur-impragnated charcoal shows high Hg sorption capacity and removes more than 95 % of the Hg but is expected to show Hg species trans-formation by microbial activity within the filter-ing system. Hg(0) stripping after Hg2+ reduction through tin filters removes more than 90 % of the Hg but does not remove Hg bound to organic complexes. No Hg species trans-formation was observed to occur in the tin filter, however soluble tin species generated by the Hg2+ reduction have to be removed from the water by an additional filtering system. Ongoing studies will investigate the long term effectiveness of both methods.

Bicontinuous microemulsions a new extraction medium for *in situ* soil remediation

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Bicontinuous microemulsions are an excellent alternative to surfactant solutions for the *in situ* extraction of contaminated soil. The advantages of microemulsions are their low interfacial tensions and their large solubilization capacity. The efficiency of microemulsions for desorbing harmful PCB (polychlorinated biphenyls) will be shown in batch and soil column experiments. PCB are nearly completely desorbed from soil in batch experiments at 10 °C. In soil column experiments the microemulsions also show high recovery rates of PCB (from 60-90%). In a technical scale-up experiment a microemulsion system was applied to an artificial aquifer (6 m long, 2.7m high, 0.4m wide) containing sand contaminated with trichloroethene. It could be demonstrated that the microemulsion penetrates much easier into structures of fine sand than surfactant solution. With less than 2 pore volumes of microemulsion more than 94 % of the pollutant could be removed.

HYDRAULIC IN-SITU REMEDIATION TECHNIQUES WITH SURFACTANTS: OPTIMIZATION OF HYDRAULIC SYSTEMS

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Objectives: (1) Development of improved hydraulic remediation systems for the extraction of contaminants at the source (optimization of hydraulics) (2) Improvement of the uniformity of the flow through inhomogeneous aquifers, using specially designed wells with packer systems (3) Determination and minimization of the permeability reductions induced by surfactants (4) Use and reuse of surfactants in technological scale (5) Minimization of consumption and costs of surfactants and energy. **Experimental setup:** Two artificial inhomogeneous aquifers with the dimensions 9 x 6 x 4.5 m (L x W x H) were constructed. One consists of 4 inclined layers of different permeability, each layer with one kind of sand. The other consists of irregular ordered blocks with different permeability. A constant ground water flow is maintained. Two contaminants are used: trichloroethene as DNAPL, Xylene as LNAPL. Several well arrangements and appropriate water treatment were used for remediation. **Results:** Tracer tests were combined with a numerical model to estimate in detail the "real" permeability of the emplaced sands. While comparing the measured and the predicted breakthrough times in the aquifer deviations due to inhomogeneities were established. The procedure of contaminant distribution (based on 378 sampling locations) was monitored during remediation. In- and outflow water was regularly sampled for an exact mass balance. After 83 days of hydraulic remediation, approximately 90% of the emplaced trichloroethene was removed. Results of the remediation of xylene using surfactants will be presented.

ENHANCEMENT OF BIODEGRADATION IN BIOLOGICALLY ACTIVATED ZONES

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Current trends in the remediation of polluted soil are towards natural attenuation in combination with the application of biologically activated zones. Natural attenuation is the overall result of physical, chemical and biological removal mechanisms, e.g. dilution, sorption and biodegradation. The actual elimination mechanism leading to the establishment of a plume that does not spread with time, is (bio)degradation. When enough space is available natural attenuation can be applied as the sole remediation measure. In most cases however, the natural attenuation option has to be combined with a biologically activated zone or a bioscreen. Various strategies to enhance the biodegradation of pollutants exist, depending on the compounds of concern, and, of course, the local circumstances at the contaminated site. Chlorinated solvents are in many cases transformed by reductive dechlorination. This process proceeds at maximal speed when the redox potential is low enough and when there is enough electron donor available to sustain the reductive reaction. There are several methods to provide the optimal conditions, including electrical stimulation and addition of carbon sources. These methods will be discussed during the presentation.

SURFACTANT SELECTION FOR ENHANCED SUBSURFACE REMEDIATION: LABORATORY AND FIELD OBSERVATIONS

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Pump-and-treat remediation of contaminated ground water is frequently limited by capillary-bound oil (residual saturation). Surfactant enhanced subsurface remediation is being evaluated to overcome this problem and thus expedite ground water cleanup. The two surfactant approaches being investigated are micellar-enhanced solubilization and mobilization via middle phase microemulsions. Relative merits of and concerns with these two approaches will be discussed, along with the importance of surfactant selection to each. Economic analyses demonstrate that minimizing surfactant losses and reusing the surfactant stream are critical to the viability of these technologies. An example of how surfactant selection can minimizie subsurface losses will be presented. Selection and design of unit processes for regenerating (decontaminating) the surfactant stream will be described, including surfactant impacts on these separation processes. Widespread implementation of these technologies requires successful scale up from laboratory results to field systems. Selected results from six field demonstrations will be presented that both illustrate the factors discussed above as well as demonstrate our ability to scale up these systems to the field. These results thus demonstrate that surfactant-based technologies can dramatically improve pump and treat remediation of residual oil zones.

HSA8

IRON SULFIDE PRECIPITATION IN A PERMEABLE REACTIVE WALL, NICKEL RIM MINE, ONTARIO, CANADA

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A permeable reactive barrier was installed in August 1995 at the Nickel Rim Mine near Sudbury, Ontario, Canada, for the passive remediation of groundwater contaminated with acid mine drainage. The reactive barrier was designed to minimize the discharge of groundwater with an acid-generating potential to a nearby lake, by removing Fe through iron sulfide precipitation and generating alkalinity. The reactive component of the barrier consists of a mixture of municipal and leaf compost and wood chips; the decomposition of organic material in the barrier creates an anaerobic environment conducive to the growth of sulfate-reducing bacteria. The results of the solid-phase extraction of the reactive material during two years of operation indicate that there is an accumulation of primarily acid volatile sulfides (e.g. amorphous iron sulfide, mackinawite, greigite) in the permeable wall. The analysis of iron sulfides precipitated on well casings by X-ray diffractometry and X-ray photoelectron spectroscopy, in combination with the porewater geochemistry, suggests that a disordered mackinawite ($Fe_{1+X}S$) phase is the primary sulfide precipitate in the barrier.

THE EFFECT OF DISSOLVED INORGANIC GROUNDWATER CONSTITUENTS ON THE REACTIVITY OF FE(O)-REACTIVE WALLS – LABORATORY STUDIES AND THERMODYNAMIC CALCULATIONS

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Zero valent iron walls provide a cost effective technology to remediate groundwater plumes contaminated with chlorinated solvents (TCE, PCE) and reducible metals (CrO_4^{2-}, TcO_4^-, UO_2^{2+}), if their reactivity and permeability is not significantly decreasing due to geochemical reactions in the long run.

Long-term column experiments were performed to study the effect of the anions chloride, phosphate, sulfate, chromate and nitrate on the degradation process of trichlorethene via zero valent iron and the water chemistry in the outflow. The presence of chloride leads to a slighly acceleration of the TCE-degradation. However sulfate and phosphate strongly decreased the degradation rates. These inhibition effects are due to the sorption of sulfate and phosphate on the Fe-oxide layers and the formation of precipitates like Vivianite or Green Rust. Thermodynamic equilibrium calculations were performed to estimate species distributions and mineral equilibria of different solution types after a passage through an iron-treatment zone. These studies may explain from the thermodynamic point of view the redox- and precipitation reactions of the column experiments and permit a prediction with regard to the long term reactivity, porosity losses and the groundwater composition in the outflow of a zero valent iron treatment zone.

CATALYTIC HYDROGENATION OF AROMATIC COMPOUNDS WITH PALLADIUM – INFLUENCE OF SUPPORT MATERIALS ON DEACTIVATION

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Catalytic hydrogenation is potentially applicable for the removal of halogenated contaminants from groundwater. A palladium on alumina catalyst was found to dehalogenate and hydrogenate a wide variety of chlorinated aromatic compounds under ambient conditions. However, ions commonly found in groundwater can cause a rapid deactivation of the metal catalyst. This research investigated the influence of support materials on catalyst deactivation in batch and column experiments. Alumina and zeolite Y in different Si/Al ratios were used as support materials. 1,2 - Dichlorobenzene was used as a chemical probe in deionized water with and without sulfite (sodium salt). Sulfite, known to be a strong "poison" for metal catalysts, caused a complete deactivation of the palladium catalyst on alumina within minutes. In contrast, the deactivation of the catalyst was significantly retarded by using a catalyst-zeolite system. The deactivation decreased with increasing Si/Al ratios of the zeolite due to the resulting higher hydrophobicity of the matrix. The long term performance of this hydrophobic catalyst was studied in column experiments using palladium impregnated pellets of zeolite Y. A highly contaminated core of brown-coal from a chemical plant was eluted directly into the catalyst column. The degradation rates were stable within the observation time of several weeks. Slight decreases in catalyst performance could be reversed by flushing the catalyst with tap water. These results indicate that hydrophobic microporous support materials such as zeolites can effectively mitigate decreasing catalyst performance due to sorption of groundwater ions.

***IN SITU* BIO-ELECTROCHEMICAL NITRATE REMOVAL FROM GROUNDWATER**

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Groundwater is an important source for the production of drinking water. However, at many places groundwater contains more than 50 mg nitrate/l, the EU and US EPA standard. To prevent adverse health effect nitrate should be removed from the water. One of the denitrification technologies currently under development is *in situ* bio-electrochemical nitrate removal from groundwater. The method is based on the construction of a vertical screen located upstream of a field with groundwater wells. The screen comprises gates with wire-netting that acts as an anode producing hydrogen gas. The hydrogen gas is dispersed in the passing water and acts as electron donor for hydrogenotrophic autotrophic microorganisms which convert nitrate into nitrogen gas. The anode is placed within one cm distance from the cathode. The oxygen produced at the anode is rapidly removed by vertical tubes. The process was demonstrated in laboratory columns filled with gravel or sand. The hydraulic residence time in the column was 0.5 day, the used voltage was 6 V and current 50 mA. The nitrate concentration decreased from 150 mg/l to less than 5 mg/l and the hardness went from 9 °D to 1 °D. Cost estimates for full scale application indicate total costs of US$ 0.15 (of which US$ 0.08 energy costs) per m^3 water with 100 - 150 mg nitrate/l. As this technology seems promising, field demonstrations are planned in 1999.

***IN SITU* BIODEGRADATION OF HEXACHLOROCYCLOHEXANE (HCH)**

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The pollution of soil and groundwater with hexachlorocyclohexane (HCH) has caused serious environmental problems. The insecticide lindane (γ-HCH) is the best known HCH isomer, although only 17% of the isomers. The remaining part consists of α-, ß- and δ-HCH, which do not have insecticide activity and therefore were discarded at production sites and in landfills. In contrast to α- and γ-HCH, ß- and δ-HCH are known to be recalcitrant towards biodegradation under anaerobic as well as aerobic conditions. However, recent research has shown that ß-HCH can be microbiologically degraded to the intermediates monochlorobenzene and benzene under anaerobic conditions. Because monochlorobenzene and benzene are both known to be biodegraded aerobically and anaerobically, complete mineralisation of all HCH isomers can be expected. Further research will therefore focus on the combination of two processes: I) (activated) anaerobic biodegradation and II) activated aerobic or intrinsic anaerobic bioremediation. Depending on the contaminated site conditions, the *intrinsic anaerobic degradation* capacity of endogenous microorganisms may be sufficient. If there is no or insufficient intrinsic biodegradation capacity for monochlorobenzene and benzene, stimulation of the degradation by an *activated aeration step* is necessary. Both process combinations are integrated into one extensive bioremediation technique: in situ remediation of groundwater by using bioscreens and intrinsic biodegradation.

HSA8 Hydrology and chemical processes - restoration of aquifers: natural and artificial attenuation

03 Redox processes in aquifers

Convener: Behra, P.
Co-Convener: Isenbeck-Schröter, M.

GEOCHEMICAL TRANSPORT MODELING OF LEACHATE ATTENUATION IN QUARTENARY SEDIMENTS DOMINATED BY PYRITE REDUCTION AND CALCITE DISSOLUTION: MODEL TESTING AGAINST FIELD DATA FROM THE TRANDUM LANDFILL, NORWAY.

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A contaminant plume from Trandum municipal landfill was investigated with respect to the distribution of redox-sensitive inorganic species in groundwater. Groundwater composition immediately below and downstream of the landfill allows for a tentative identification of redox zones based on oxidized and reduced forms of Fe, Mn, N and S. A methanogenic zone is not observed. Uncontaminated groundwater has a chemical signature indicative of calcite and pyrite weathering, with weathering horizons located 3 meters below the water table separating an oxic and anoxic zone. This horizon has been successfully reproduced with a one dimensional geochemical advective transport model. The one-dimensional model provides a tool for assessing the importance of natural geo- and hydrochemical stratification and influence on the fate of leachate migration in the aquifer. At the plume scale, preliminary simulation results using the PHAST model, which couple PHREEQC and the HST3D flow and transport model are utilized for the interpretation of contaminant attenuation.

EFFECT OF pH ON SURFACE COMPOSITION OF PYRITE

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It is widely accepted that pyrite FeS_2 could play a key role in various environmental compartments. The wet oxidation of pyrite has been studied in batch experiments in a large range of pH (3-12), with trace oxygen, ionic strength fixed by $NaNO_3$ or NaCl, contact time varying between 12 h and 10 days. Surface analysis of the samples has been performed using X-ray Photoelectron Spectroscopy whereas quantification and speciation of the aqueous species have been studied by ICP-AES, HPLC and UV-Vis Spectrometry. In acidic conditions (pH < 4), pyrite presents an iron deficient surface composition $Fe_{1-x}S_2$, while Fe(II) and sulphate are released into solution. When the pH increases there is no more iron in solution, and other oxidised sulphur species like sulphite and thiosulphate appear. An overlayer of iron (hydr)oxide with a stoichiometry close to FeOOH grows onto the surface following an island growth mechanism. However this overlayer does not passivate the sample against further oxidation, and a decrease in pH is observed.

TRENDS IN THE TRANSFORMATIONS OF HALOGENATED ORGANIC POLLUTANTS BY IRON SULFIDE

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The objective of this work was to quantify the rates and products of transformation of several halogenated organic compounds by the common mineral iron sulfide (FeS). Compounds studied include: hexachloroethane, pentachloroethane, 1,1,1,2- and 1,1,2,2-tetrachloroethanes, 1,1,1-trichloroethane, tetrachloromethane, tetrachloroethylene, trichloroethylene, and tribromomethane. All experiments were conducted under anoxic conditions characteristic of environments where FeS occurs naturally. Half-lives for transformation of these halogenated compounds by FeS were on the order of hours to weeks. The results of these experiments indicate that several environmentally-relevant transformations, including reductive dehalogenation, dihaloelimination, and substitution, may be mediated by FeS, depending on the properties of the halogenated organic compound. The properties that were found to influence reaction rates and pathways include one-electron reduction potentials, carbon-halogen bond strengths, and the tendency for adsorption of the halogenated organic compound to the FeS surface. The influence of these properties on the potential for transformation of halogenated organic pollutants in the environment will be addressed in the presentation.

ABIOTIC REDUCTION OF ORGANIC POLLUTANTS UNDER FERROGENIC CONDIOTIONS

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In many anoxic aquifers iron(III)(hydr)oxide minerals are involved as electron acceptors in biogeochemical redox processes. In recent years, the significance for pollutant reduction of ferrous iron species present at surfaces of Fe(III)(hydr)oxides in anoxic systems has been recognised. In contrast to the reactivity of minerals containing structural iron(II), which often is very low once the reactive surface sites are exhausted, the high reactivity of surface-bound Fe(II) species can be maintained over long periods of time since such species may continuously be regenerated by uptake of Fe(II) from solution or by the activity or iron reducing microorganisms. Based on results of laboratory batch and column studies, we will discuss factors that affect the reactivity and regeneration of surface-bound ferrous iron species with respect to pollutant reduction. The organic contaminants studied include halogenated solvents and nitrated aromatic compounds.

RATES OF TERMINAL ELECTRON ACCEPTING PROCESSES IN AN ANOXIC AQUIFER

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Rates have been determined for Fe-reduction, sulfate reduction and methanogenesis from acetate and carbondioxide. Also rates of acetate and methane oxidation have been measured. Measurements were made directly through injection of radioactive tracers, or in the case of Fe-reduction - estimated from concentration profiles. The data show that the main pathway for methanogenesis is through reduction of carbondioxide, and for Fe-reduction oxidation of acetate is a major pathway. Methane oxidation is of minor importance. The obtained rates are at most a few mM/yr. and comparison with the concentrations of the intermediates acetate, formate and hydrogen shows that the pool of acetate is cycled in about a day while hydrogen is cycled in about a minute. It seems feasible to view the system as being at a partial equilibrium with the initial breakdown of organic matter being the rate limitting step and the terminal eletron accepting processes (TEAPs) occuring at close to thermodynamic equilibrium. This is supported by calculated in situ Gibbs free energies of the TEAPs, of around -4kJ/mole of electrons.

FERROGENOUS MINERALS FORMATION IN PURE CULTURE OF FE(III) REDUCING BACTERIA

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The formation of vivianite, $Fe_3(PO_4)_2 8H_2O$ in an anaerobic culture of *Shewanella putrefaciens* using Fe(III) citrate as terminal electron acceptor and lactate as electron donor and carbon source was described. Minerals were characterised by using Mössbauer spectroscopy and X-ray diffraction. The redox potential of the culture decrease as long as Fe(III) was reduced. Measurements of iron indicated that vivianite produced after exponential bacterial growth contained only 10% of the total iron in the culture. The rest of iron was constituted by a soluble form of Fe(II) and a residual of Fe(III) citrate.
Reduction of lepidocrocite, a crystallised ferric oxyhydroxide, by the same bacterial strain, was also analysed. The reduction of this mineral was much slower than Fe(III) citrate but was followed by an continuous increase of pH (from 7.0 to 8.2). Availability of crystallised Fe(III) oxyhydroxide like lepidocrocite to reductive process will be discussed.

REDOX CONDITION HETEROGENEITY AND ITS INFLUENCE ON CHEMICAL, MICROBIOLOGICAL AND HYDRODYNAMIC CHARACTERISTICS IN A WASTE PLUME (W. SWITZERLAND)

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Diverse and widespread reduced conditions exist in the Seeland aquifer (70 km2), an important public water supply. To the SE, these are mainly due to decades of seepage, rich in degradable organics, from unlined discharge sites at a sugar refinery. Studies in the 1950s and 1970s showed an extended plume of reduced groundwater deteriorating water supplies. The aquifer consists of about 20 m of inter-layered gravel, sand, silt and clay which are of lacustrine and fluvio-glacial origin. This heterogeneity makes it difficult to determine exact horizontal/vertical plume extent, its Redox conditions and the transport of contaminants DOC, Fe, Mn and K. Recent regional surveys show limited rehabilitation from the infiltrating Alte Aare River. In 1997, the Redox chemistry and the microbial activity were evaluated in 10 wells at a field site about 1 km from the original ponds. Redox conditions varied strongly even over the limited distance of 70 m and between the shallow and deeper aquifer layers. Eh varied from -180 mV to +61 mV and dissolved oxygen from 5 to 25 % saturation. Oxygen added to observation wells caused rapid indigenous iron and manganese oxidizing bacterial growth (Siderocapsa sp., Gallionella sp., Leptothrix sp.) and high-permeability (10-2 m/s) gravel plugged in several hours. Ongoing work will document the iron, manganese, sulfate and bacterial species and investigate the mechanism of pathway clogging.

HYDRO-GEOCHEMICAL MODELLING OF A REACTOR ZONE IN BANGOMBE (GABON): CHARACTERIZATION OF REDOX PROCESSES

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The hydro-geochemical modelling of the Bangombé site (Oklo, Gabon) based on the groundwater analysed for major and trace elements and for isotopes allows the characterization of the geochemical behaviour of dissolved uranium. The modelling is based on the results of three campaigns, held in March 1993, July 1994 and September 1996. The geochemical modelling of the solutions sampled in March 1993, shows that the groundwater leaching the Bangombé reactor zone can possibly result from the mixing of deep, reduced water (BAX01), close to equilibrium with uraninite and coffinite (U^{IV}) and oxidized surficial water (BAX06) showing a low content in uranium (U^{VI}). Within the reactor zone, the groundwater (BAX03) shows an equilibrium with respect to uraninite and coffinite under buffered conditions regulated by Fe^{II}/Fe^{III} ratio characterized by an equilibrium between siderite/ferrihydrite found in rock mineralogy. The reduced conditions and uranium concentrations are such that precipitation can occur in the reactor zone. The geochemical landscape for the 1996 campaign remains similar, apart from the fact that the waters are more oxidized. Thus, the uranium content has decreased in the deep water and has increased in the shallow waters. The solutions sampled in July 1994 show intermediate redox conditions between 1993 and 1996. This work is in the EU Nuclear Fission Safety programme assigned Natural Analogue research activities (started June 1996).

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THE REDUCTION OF CHROMATE IONS BY FE(II) SPECIES

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The reduction of chromate ions by Fe^{2+}_{aq} cation, $Fe(OH)_2$ and the Fe(II)-Fe(III) hydroxysulphate known as Green Rust two (GR2) has been studied for different $Fe(II)/CrO_4^{2-}$ ratios (1, 0.5 or 0.25). In a first step, Fe(II) is oxidized into Fe(III) whereas Cr(VI) is reduced into Cr(III). This first oxidation stage is fast and is followed by a slower oxidation step due to the atmospheric oxygen. In these experiments, mass balance (ICP-AES) demonstrates that chromium is totally incorporated into the solid matrix. The nature of the final solid phases, analysed by X-ray diffraction, Mössbauer and Raman spectroscopies, depends on the initial ferrous compound and on the $Fe(II)/CrO_4^{2-}$ ratio. A poorly crystallized or amorphous product is always observed. It looks similar to δ-FeOOH when $Fe(OH)_2$ is the initial ferrous phase and it is the end-product of the instantaneous oxidation of Fe(II) by CrO_4^{2-}. It contains Cr(III) and could probably play a role in the behaviour of chromium in the aquifers. In contrast, well crystallized magnetite - or goethite - is produced during the subsequent oxidation of the remaining Fe(II) by atmospheric O_2. These last phases do not contain chromium.

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CATALYTIC ROLE OF MINERAL SURFACES IN REDOX REACTIONS IN SUBSURFACE ENVIRONMENT

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In natural systems, iron strongly influences the behaviour of pollutants such as heavy metals, and particularly, in subsurface anoxic aquifers, dissolved iron plays a critical role. The reactivity of an aqueous solution system containing U(VI) (as $UO_2(OH)_2$) and Fe(II), with or without suspended hematite particles present, was investigated in strict anoxic conditions. We have shown how reduction reactions by Fe(II) are catalysed by the presence of mineral particles. It appears that the adsorption of Fe^{2+} ions onto hematite particles creates very reactive reductant species. In order to fully describe the reduction mechanism, uranyl reduction was followed at various experimental conditions, different U(VI) and Fe(II) total concentrations and different pH values. A kinetic law, similar to that observed for the oxygenation of Fe(II) has been obtained. The products of the reactions have been identified by FT-IR spectroscopy and we can suggest that ferrous iron precipitated together with the uraninite U(IV). This can explain the strong decrease of uranium mobility in natural system in the presence of hydrous ferric oxides. Moreover, the application of this mechanism to mineral ore formation or to the confinement of nuclear waste can be discussed.

ASPECTS OF CONTAMINANTS MIGRATION FROM WASTE ROCK OF KHIBINY MINES

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Objects of research were ultrabasic alkaline waste rocks of Khibiny open pits. Objective of the work is to assess degree of negative influence of waste rocks on ecological safety of natural waters on surrounding areas. Research includes: 1) laboratory dissolution of waste rocks under various physico-chemical (pH, T, composition of solution) and hydrodynamic (velocity of filtration) conditions; 2) determination of absorption capacity of Quaternary deposits with relation to Sr, Fe, Al; 3) field monitoring of surface and ground water quality of the area. There were obtained dissolution rates of the following chemical species F, PO4, Al, Sr, Fe, Mn and dependencies between dissolution rate of species and parameters of the environment. Special attention was paid to speciation of metals. Using information about quantity of atmospheric precipitation on the area, quantity and dissolution rates of selected waste rocks there was done an estimate of pollution entering from waste rocks into underlined layers. Experiments on adsorption of Sr, Fe, Al carried out on basic types of Quaternary deposits indicate that Quaternary deposits of the area with typical depth about 8 meters have high potential on ground water purification from Fe and Sr. Concentrations of elements in water samples regularly collected over the area are in good coincidence with predicted from laboratory data. The results enable to conclude that the most danger to water quality from waste rocks is represented in emission of conservative compounds of fluorine. Iron, strontium and aluminium have much less migration ability and concentrations in the water being adsorbed (Sr and Fe) or precipitated (Al) in the aquifer.

MIGRATION BEHAVIOR OF TRACE METALS UNDER CHANGING REDOX CONDITIONS IN THE SHALLOW AQUIFER OF A MESOSCALE ODER RIVER POLDER (ODERBRUCH)

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The Oderbruch polder includes an area of 800 km^2 and is the greatest river polder in Germany. The approach of geochemical process studies is a better understanding of substance dynamics at the contact zone between the anaerobe groundwater and surfacewater of a vast drainage system with ditches and small rivers. Induced by seasonal changing of water levels, different ex- and infiltration conditions occur which strongly influence the hydrochemical conditions of the aquifer at the interface of groundwater/surfacewater.
Intensive hydraulic and hydrochemical field investigations were carried out to define and characterize the spatial distribution of redox zones. In connection with column experiments the migration behavior of As, Cd, Fe, Hg and Zn was quantified and balanced. The use of selective chemical extraction analysis in connection with radioactive tracer techniques allows the characterization of trace metals migration behavior and a determination of solution and precipitation processes of heavy metals and their surface interactions with coatings and minerals in redox transition zones.

BONDING AND MOBILITY OF HEAVY METALS IN ROASTED PYRITES - A COMPARISON BETWEEN SEQUENTIAL EXTRACTION AND LONG-TERM ELUTION EXPERIMENTS

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In addition to long-term elutions experiments (2 years) and mineralogical studies of roasted pyrites a sequential extraction completed the knowledge about the leaching behaviour of these materials, especially the assesment for groundwater. The pyrites of different ages originated mostly from the Bohemian Massif and were all processed in the same industrial way in southern Bavaria, Germany. Only the depostion of roasted pyrites and therefore the weathering conditons differed. The ages of the roasted pyrites reached from actual, 10, 40 to 60 years. A 8 steps sequencial extraction starting with water and ending with aqua regio extraction specified the bonding and mobility of heavy metalls in these roasted pyrites. The roasted pyrites showed no homogeous development of bonding according to their age. There are two crucial points: the water soluble part and the part of heavy metals that are fixed in iron minerals and soluble in aqua regio. The last part increased with the age of the material. The 40 years old roasted pyrite showed a signicant lower leaching behavior than the other materials though its chemical composition is equal to the actual roasted pyrite. In the case of As, Cd, Mn and Ni the sequential extraction confirmed the results of the elution experiments. On the other hand, the results of the elutions experiments for Co, Cu, Fe, Pb and Zn were not representative for the water soluble part in the materials. The increasing part of stronger fixed heavy metals with the age of the material confirmed with the results of the mineralogical studies. They stated recristallisation processes during weathering and aging of the material into coating minerals including fixation of heavy metals.

REDOX MEASUREMENTS - A THEORETICAL CONSIDERATION BASED ON ELECTRODE KINETICS

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The intention of redox measurements is the characterisation of an aqueous solution with respect to its electron transfer intensity. Implicit in this approach is the assumption that the measured potential is identical or at least close to equilibrium potential. However, from a theoretical point of view, the measured potential is a parameter based on electrode kinetics, which can be derived from electrochemistry, i. e. the Butler-Volmer-Equation.
The measured potential is by definition a mixed potential to which each redox couple contributes to a various extent. The relative contribution of a single redox couple is controlled by at least three parameters:

- concentration of the redox species,
- standard rate constant for the electron transfer between the dissolved species and the electrode material,
- the potential difference (usually refered to as overvoltage) between the mixed potential which establishes at the electrode and the Nernst potential of a single redox couple.

In this talk, the influence of these parameters on the electrode potential and its implication for the measurement of redox potentials will be discussed.

REDOX CHEMISTRY OF IRON AND SULFUR AT THE INTERFACE BETWEEN SEDIMENT AND GROUND-WATER OF ACID MINE LAKES

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Acid mine lakes have formed after flooding of former open pit mines with ground water, which transports high amounts of ferrous iron and sulfate into the lake water. Upon oxidation of ferrous iron and subsequent hydrolysis of ferric iron, acidification of the lake water to pH values below 3 occurs. Following the hypothesis that microbial alkalinity formation within the sediments of these lakes might neutralize the acidity, we studied the biogeochemistry of iron and sulfur at the interface between sediment and ground water and in lake water of several acid mine lakes.
In the lake water an intensive redox cycling of iron exists, with high sedimentation rates of ferric (hydr)oxides. The sediments are enriched in iron (up to 400 mg/g d. m.) and release ferrous iron from microbial (and abiotic ?) iron (hydr)oxide reduction. Within the sediments, sharp redox and pH gradients (from pH 3 close to the sediment-lake water interface to pH 6.5) build up. Despite high concentrations of reactive iron, also sulfate is microbially reduced. Subsequently, pyrite formation occurs under recent conditions, which signifies the reversal of the pyrite oxidation process in the aquifer. Storage of reduced sulfur in the sediments points to at least partial neutralisation of the acidity by internal processes. However, the overall process seems to be limited by the availability of organic carbon to heterotrophic microbial activity.

RARE EARTH ELEMENTS AS TRACERS OF REDOX PROCESSES IN SHALLOW GROUNDWATERS

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The rare earth elements (REE) were analyzed in shallow groundwaters from a small agricultural catchment in order to investigate their use as tracers of redox processes and groundwater flow. Previous hydrological and hydrochemical studies identified two contrasted domains in this catchment: (i) a hillslope zone comprising well drained soils where oxidizing conditions prevail, and (ii) a bottomland zone characterized by waterlogged soils where conditions are more reducing. This contrast in hydrological conditions and redox environments is reflected in the REE profiles of local shallow groundwaters. First, a negative Ce anomaly has been found systematically in groundwaters from the hillslope zone while groundwaters from the bottomland domain have flat LREE profiles with no Ce anomaly. Second, average REE concentrations (ΣREEs) are systematically higher in bottomland waters than in hillslope waters. Third, while waters from the hillslope have flat shale-normalized REE profiles, bottomland groundwaters exhibit fractionated REE profiles, showing marked enrichment of the LREEs over the HREEs. The difference in redox conditions allows an explanation on the contrasted behavior of Ce in these waters. Among the REE, Ce can occur as Ce^{3+} like the majority of lanthanides, or as Ce^{4+} in oxidizing conditions. If soluble Ce^{3+} is oxidized to Ce^{4+}, it can precipitate from solution to very insoluble Ce-oxides. Consequently the solution shows negative Ce-anomaly. Alternatively, if the environment is reducing as in the bottomland zone of the catchment, all the Ce occur as Ce^{3+}. Consequently, the solution shows no negative Ce anomaly.

ANALYSES OF THE ANAEROBIC DEGRADATION OF WATER-SOLUBLE ORGANIC COMPOUNDS IN AQUIFIC ENVIRONMENTS

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A study was performed to analyse the anaerobic degradation of water-soluble organic compounds containing water-soluble parts of deicing chemicals and Jet fuels in aquific environments, which often does occur in the saturated zone of the aquifer below the water-table. Such process is often subject to several constraints, such as the cycling of redox-sensitive inorganic oxidants and microorganisms respiration as well as environmental conditions including sediments, temperature, groundwater flow, pH, and redox potential. Microorganisms as stimulators for oxidants are supposed to play a major significant role in dominating the anaerobic degradation of organic compounds which always couples the reduction of oxidants. Typical inorganic compounds which act as terminal electron-accepting oxidants in aquific environments include nitrate, Fe(III) and Mn(IV) oxides, sulfate which possess various biological activities, thus affecting the anaerobic degradation of organic compounds differently. Whereas the cycling of these inorganic compounds is experimentally mediated mainly by microbial processes. The successful isolation of anaerobic bactria in aquific environments is confirmed that the reduction of inorganic compounds coupling with the oxidation of organic compounds is microbially catalyzed under anaerobic conditions. The attenuation of water-soluble organic compounds appeared to be related to the microbial reduction of inorganic compounds. The geochemical modeling of contaminated pore water chemistry in relation to mineral assemblages in aquific environments is one of the best methods available for quantifying what microbial processes regulate the anaerobic degradation of organic compounds in aquific environments. The study concluded that anaerobic degradation of organic compounds is much different than that of aerobic degradation. New research relevant to the anaerobic degradation of organic compounds in aquific environments is still stimulated.

HSA9 Hydrology and applied mathematics

01 Process representation in hydrological models - can it be achieved?

Convener: Gallart, F.
Co-Convener: White, S.M.

A physically based approach of urban rainfall-runoff modeling

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New environmental requirements, such as reduction of urban storm water pollution, suggest to address the response of urban catchment to any rainfall event, and more specifically to every day rain event. This research need is emphasized by experimental data wich confirm the complexity of the urban rainfall-runoff transformation, widely affected by still little-known mechanisms : contribution of so called 'impervious' surfaces to the flow, contribution of pervious surfaces to the flow, urban water exchanges between soil and atmosphere. A physically based approach appears suited to represent those mechanisms and to study their hydrological influence. Considering the complexity of the urban area, the model developped here is a simplified two dimensional scheme representing a cross-section of an urban catchment and it is constituted by the following main elements : a natural soil, a house, a street and a central trench, located below the street, in wich the sewer system is laying. Numericals methods (finite elements) based on the equation governing the waterflow in porous media are used to study water circulation and resulting outflow in this scheme. The processes of interception, infiltration, evapotranspiration, preferential flow, drainage by the sewer system and groundwater saturated flow are represented. The communication will describe the model and show results of a simulated hydrological year.

COMPARATIVE VALIDATION OF HYDROLOGICAL MODELS: PRELIMINARY RESULTS

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The preliminary results of a comparative validation exercise for five hydrological modelling systems are presented (BROOK, SACRAMENTO, TOPMODEL, TOPKAPI, SHETRAN). These range in complexity from a simple lumped conceptual approach to a fully physically-based, distributed approach. The modelling systems were subject to a split-sample validation test using data from the Cal Rodó research catchment, Catalonia, north-eastern Spain. Model discharge and catchment water reserve results are presented and compared with observed data.

MODEL IDENTIFIABILITY AND CONSTRAINING PROCESS REPRESENTATIONS IN MODELLING RUNOFF PRODUCTION

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Much of what happens in catchments during rainstorms is essentially unknowable since we do not have the measurement techniques available to be able to follow the dynamics of different processes at hillslope or catchment scales. Much of what has been learned from small scale process experiments, particularly in the field, has added to the complexity of our perceptions of hydrological processes but has not clarified how to model that complexity at a new site. We are therefore in a position where it would appear to be valuable to seek ways of constraining the feasible process representations of a site, in terms of both model structure and parameterisations. Some example studies will be given of trying to use water table data and contributing area data as well as discharge data to constrain models in this way. Two main issues arise: one is the interaction between model structures and appropriate parameter values and uncertainty, the other is the introduction of heterogeneous parameters where there are spatially distributed predictions available with which to condition parameters. It is suggested that a useful concept in the application of process models is that of a mapping of the landscape space into a space of feasible models, in which field observations are used to limit that model space. This then provides a framework for the plannig of measurement programs with the greatest value in constraining the feasible model space, and hence the resulting (uncertain) predictions.

PROBLEMS ASSOCIATED WITH THE PARAMETERIZATION OF PHYSICALLY-BASED HYDROLOGICAL MODELS: AN EXAMPLE

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The basis of the philosophy behind physically-based hydrological models is that because they incorporate physics-based representations of hydrological processes they can be parameterized directly from observations made in the field or laboratory without the need for calibration. However, in reality, this is rarely, if ever, achieved. The problems of parameterization of such models have been thoroughly discussed in the hydrological literature; these fall broadly into two categories:

- a lack of information about the catchment being modelled
- the mismatch of scale between field measurements and model grid scale

These problems are discussed with reference to the application of the physically-based distributed modelling system SHETRAN to Cal Rodó, a small catchment in an area of largely abandoned agricultural land in the Catalan Pre-Pyrenees, north-eastern Spain.

AN ASSESSMENT OF THREE MODELS ABILITY TO REPRESENTATE THE RAINFALL-RUNOFF RELATIONSHIPS FROM SEMIARID AREAS

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The majority of the rainfall-runoff models have been built for temperate or wet catchments where modelling is more straightforward, or where the hydrological response only involve a subset of the processes which occur in arid and semiarid regions. This paper describes the comparison of three modelling approaches: a simple process equation (TANH model); a daily runoff simulation model based on soil water deficit calculations (KARN model; Karnieli and Ben Asher, 1993); and a simple conceptual daily rainfall-runoff model (SFB model; Boughton, 1968) to evaluate runoff prediction capabilities and the ability for studying hydrological response of four zero-order microcatchments in a semiarid environment (Murcia, SE Spain). the runoff prediction capability was low for all the modelling approaches. Nash efficiency coefficient was less than 0.83 in all the microcatchments. Regardless of the model used, the runoff was clearly underestimated in medium, high intensity (> 10 mm h^{-1}) storm events whereas it was overestimated in long, low intensity storm events (< 10 mm h^{-1}). The KARN model performed the best to simulate runoff from low intensity rainfall whereas the TANH and SFB models were the best in the simulation of runoff from medium-high intensity storm events.
Unlike the runoff prediction ability, the use of these models as tools to improve our understanding of the hydrological processes in semiarid areas was satisfactory. The calibrated parameters were closely related with the measured physical soil properties and the runoff generation mechanisms detected in the microcatchments.

FIELD EXPERIMENT IN AN EFFORT OF MODELLING

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The intensive development of numerical modelling of natural processes caused new stage in the field measurements' investigations - field experiment in the aim of following numerical modelling. This process is very complicated- because of big difference between real field measurements' problems - and physical processes for numerical modelling, between real possibilities - and needed data, between professional experimentators - and programmists. Especially important became the co-operation between them on the stage of numerical modelling verification, when "modellier" must point to experimentator a great number of significant details.

In Atlantic Branch of P.P.Shirshov institute of Oceanology there is a special group of Numerical Modelling, which includes specialists both in physics, numerical modelling, chemistry, biology - and field experiment in the aim of modelling (special experiments during the field season and also monitoring programme).

Specialists of this group among other have the experience in MIKE21- numerical model for Vistula Lagoon calibration and verification. Last summer took place a special program for investigation of Vistula spit influence on the fields of wind and wave -

in an effort to estimate the mistake in incoming to MIKE21 wind data and to compare natural wave field - with calculated ones.

INTERACTION BETWEEN HYDROLOGICAL MODELLING AND FIELD WORK AT THE CATCHMENT SCALE: THE VAHMPIRE PROJECT

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The VAHMPIRE project (VAlidating Hydrological Models using Process studies and Internal data from Research basins), funded by the EC, is a commmittment of modellers and field hydrologists to collaborate in improving both hydrological modelling and field observations. The main steps of this collaborative work are the following:

1) Realization of joint field campaigns, when both field hydrologists and modellers work together in the field to gather field data for model calibration

2) Application and comparison of different kinds of models (SHETRAN, TOPMODEL, TOPKAPI, BROOK, SACRAMENTO) to the same catchments.

3) Validation of model results against hydrographs as well as internal state variables and processes (soil moisture and tensiometry, phreatic levels, actual evapotranspiration).

4) Feedback of model limitations to parameter and structure improvement, as well as to new questions on catchment processes.

Research on scale problems are also addressed, especially regarding the role of field features that cannot be represented by the conventional grid structure and methods for monitoring and upscaling internal state variables.

TOPKAPI: A NEW APPROACH TO RAINFALL-RUNOFF MODELLING

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The distributed version of a newly developed physically based rainfall-runoff model, TOPKAPI, is applied to four different basins, the upper Reno catchment (Italy), having an area of about 1,000 km^2, represented by a grid cell resolution of 400*400 m, and three experimental basins: Cal Rodò, Can Vila and Ca l'Isard (Spain), having respectively an area of about 4 km^2, 0.5 km^2 and 1.3 km^2, and grid cell resolution of 20*20 m. Application of the model to the three latter basins is made within the framework of the EC VAHMPIRE project. The model is based on a kinematic representation of flow which accounts for the topography and the geo-morphological characteristics of the catchment, integrated over each grid cell, thus leading to a cascade of non-linear reservoirs. Purpose of this work is firstly to control the effectiveness of the soil-surface-channel interchange mechanisms that are represented, and to establish the opportunity of a more detailed description of the soil processes, namely a second soil layer. The work is also aimed at testing the suitability of the model at different scales by considering the effect of lumping on the parameters representing the soil properies and the surface and channel roughness when moving from the distributed to the lumped version of the model. The model was in fact formulated to finally assume a lumped form, in which only the total water content stored in the catchment would be the state variable governing the dynamics of the saturated contributing area for the formation of runoff as well as the control mechanism for evapo-transpiration and percolation.

HYDRODYNAMIC METHODS FOR EVALUATION OF FIELD OF SATURATION BY THE OIL A STRATUM

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Determination of the filtrational fields (hydroconductivity and piezoconductivity) of deposits is an important problem of checking and development managing of the productive collectors. This problem is solved successfully by the means of hydrodynamic methods : differential analysis of the history data of development of a deposits and industrial tomography (hydrohearing) of stratum by the method of filtrational waves of pressure (FWP). The maps of filtrational fields (on the example of area of Beresov area of Romashkino oil deposit) making on rezults of differential analysis and industrial tomography of stratum by FWP method within the range of frequencies from 10^{-2} to 10^{-4} Hzs and stratum pressure from 15 to 19 MPa allow to value the fields of rest oil saturation and define optimum conditions of exploitation the water saturated stratum with provision for their own well-marked spottinesses in the thickness and permeability.

THE CONSTRUCTION OF THE RATING CURVE IN RIVER CROSS SECTIONS BY USING LEVEL DATA AND A PARAMETERIZED FORMULATION OF THE DE SAINT VENANT EQUATIONS.

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The construction of a rating curve needs a complex and extensive sequence of simultaneous level and discharge measurements. Current technology allows for low cost and easy level measurement while the discharge measurement remains difficult and expensive: thus, it is rarely performed and usually not in flood conditions because of lack of safety, variability of the phenomenon during the measurement phase and difficulty of activating the measurement team in the due time. As a consequence, long series of levels are frequently available for a river reach while the information on the rating curves is incomplete or unrealistic.

A mathematical methodology for approaching the above-mentioned problem is proposed. In the case of a river where at least one rating curve is reliable, this methodology allows a rating curve to be established or validated or extended to the range of the high discharges, in all those sections where level measurements are sampled and memorised at a short time step. Use is made of the full De Saint Venant equations parameterized in such a way that they can be numerically integrated in the time-space domain even without knowing the cross sections of the river. Finally, a practical application to a reach of the Po river, where six hydrometers are available, completes the presentation of the proposed methodology.

HYDROLOGIC SIMILARITY: DIMENSIONLESS SIMILARITY PARAMETERS OBTAINED FROM KINEROS MODEL

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It has been widely shown that adjacent catchments subject to apparently similar conditions can have different hydrological response. If catchments can be classified in terms of the similarity on their runoff response, models can be developed to suit the actual hydrological behaviour on a given catchment. Similarity between catchments can be quantified in terms of physically measurable parameters that reflect their hydrological behaviour in the same way as the Froude and Reynolds numbers has been used to characterize flows regimes in fluids mechanics.

Three similarity parameters are obtained from KINEROS model by casting the model equations into a dimensionless form through a inspectional analysis. These similarity parameters characterize catchments in terms of topography and soil hydraulic properties. Four small monitored catchments in semiarid south-eastern Spain with field measured soil properties and topography and known runoff response has been used to test the similarity parameters. The results show that two groups of catchments can be observed in terms of similarity parameters which fits with the observed hydrological behaviour of the experimental catchments.

DIGITAL TERRAIN ANALYSIS OF THE HAUTE-MENTUE CATCHMENT (SWITZERLAND) AND SCALE EFFECT FOR HYDROLOGICAL MODELISATION WITH TOPMODEL

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It is widely recognised that the topography plays an important role on the generation of runoff. The scale of digital elevation model has been found to have some impacts on the results of hydrological modelling in several studies. In particular it has been shown that the representation of the statistical distribution of the topographic index used by TOPMODEL is sensitive to the scale of the digital terrain model. The objectives of this study are to develop an analysis of the topography and scale effect for the Haute-Mentue catchment and to test the role of different time and space resolution on the result of parameter calibration. Secondly, we developed an analytical form for the analysis of watershed geometry impact on the calculus of topographic index.

The major results are that the spatial and temporal scale are important for the parameter values, but not determinant for the modelling results if we adopt a pertinent methodology for the determination of digital watershed representation. Another point is that it is possible to use numerical experiments to examine and evaluate the impact of some geometrical parameter on the determination of topographic index and water level. In the future, we will be able to propose a new approach of the hydrological processes based on scale analysis and coupling numerical and terrain experiments.

UNCERTAINTY ANALYSIS OF GEOCHEMICAL MIXING MODELS AND IMPLICATIONS FOR PROCESSES CONCEPTUALISATION

Jörin, I. Iorgulescu and A. Musy (Soil and Water Management Institute, Swiss Federal Institute of Technology, CH-1015 Lausanne, Switzerland)

Hydrograph separation using mass balance equations for water and chemical tracers to determine runoff sources in river discharge is a widely used technique in hydrology. Nevertheless during the last years, the environmental tracing techniques or more particularly their hypotheses have been discussed and reconsidered. According to these discussions the model conception of hydrograph separation has advanced. The current trend is for three components mixing models. These models are often based on chemical tracers, but in fact it subsists some uncertainty concerning their behaviour and therefore on chemical components concentrations. This uncertainty may affect hydrograph separation. So it seems important to incorporate it in application of natural tracer mixing models. The program AIDH, developed by the Soil and Water Management Institute, estimate uncertainty of mixing models results. This program is based on a Monte Carlo analysis. This approach does not consider the true uncertainty, which depends on the validity of model hypotheses. In the case of Haute-Mentue hydrograph separation, the true uncertainty was investigated by alternative hypotheses. In this particular case, a mixing model, which considers a spatial and temporal variability of chemical components content, was retained. It will be discussed how this model and uncertainty considerations affect processes conceptualisation, in comparison with previous models.

DEVELOPMENT OF ENERGY AND WATER BALANCE SCHEMES: A NEW MODIFICATION AND ITS PRACTICAL APPLICATIONS

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Today it is created a great number of mathematical models for prediction of changings of evapotranspiration, water consumption and provision with water in agriculture. The most well grounded theoretical way of creation of adequate model of processes in "groundwater-soil-plants-atmosphere" system is a calculation of energy and water balance equations jointly. The semi-empirical energy water balance scheme is put orward for the calculation of water consumption by the agricultural cultures, moisture storage of the active soil layer and irrigation rates by authors.

SCALING EFFECTS ON RUNOFF AND MOISTURE CONTENT IN A GIS-BASED, VARIABLE-SOURCE-AREA HYDROLOGY MODEL

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Recent research on soil chemical and biological dynamics in mixed landscapes has shown that the distributions of soil moisture and water transport are crucial for environmental management. We examine the effect of scaling on soil water content for a grid based, spatially-explicit, variable-source-area hydrology model in a watershed in central New York. Data on topography, soil-type and land use were input at grid sizes from 10 to 600 m. Output data consisted of runoff and the spatial pattern of soil moisture. Simulation results showed higher average soil water contents for large grid sizes, because curvature of the land and (to a lesser degree) slope decreased with increasing grid size. Higher moisture contents, in turn, increased evaporation and decreased (slightly) the runoff. Larger grid sizes also decreased the spatial variability of moisture content, especially during dry periods. Scaling-up did not affect the distribution of land use and soil type. The results show that relatively simple mass balance equations can realistically represent the moisture distribution and runoff within watersheds that have shallow and sloping soils, provided that spatial distribution of slope is represented accurately.

FROM POINT FIELD MEASUREMENTS TO CATCHMENT DATA SETS FOR INTERNAL VALIDATION OF MODELS. I- EXAMPLE OF THE CATCHMENT WATER RESERVE

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The use of catchment internal data for model validation is of major interest if the purpose of the model is to simulate properly the whole behaviour of the catchment and not only to fit resulting hydrographs. However the problem is generally to find an adequate way to compare models outputs with field points measurements. Even if the comparison between observed and simulated data can be realised on relative changes rather than on absolute values, to reduce the effect of model structure on the validation, there?s still a need for catchment internal variable for the validation. Within the VAHMPIRE project, a methodology to estimate catchment water reserve from field measurements has been therefore set up for a set of 3 nested subcatchments in the Spanish Pyrenees, using catchment available information (landuse, soil depth, topography) and soil moisture content measured by TDR technique. The preliminary results obtained have been tested against the information given by the analysis of the recession curves as well as against intensive field measurements.

FROM POINT FIELD MEASUREMENTS TO CATCHMENT DATA SETS FOR INTERNAL VALIDATION OF MODELS. II EXAMPLE OF RAINFALL INTERCEPTION

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In the framework of the VAHMPIRE project the internal validation of hydrological models using field measurements is of major interest as it provides information on model shortcomings and represents a step forward in model development. One of the main tasks is to determine the way to generalise the representativeness of point field measurements both for parametrization and validation of models.
The validation of a Rutter type interception model, used in the SHETRAN hydrological modelling system, for the simulation of rainfall interception is presented here. The first step is the validation of a "blind run" of the model, performed with uniform forest parameters obtained from the literature. The second step is the validation of a model run with spatially distributed information of forest characteristics based on field observations.

The modelling of the water cycle within a GIS based SVAT-model framework

The process-oriented multiscale evapotranspiration model PROMET developed at the Institute of Geography, University of Munich, is applied for the Ammer basin (approx. 700 km²) in the alpine forelands of Germany. The physically based soil-vegetation-atmosphere-transfer model calculates hourly actual evapotranspiration rates along with the soil moisture for a 10-year time series. A rainfall-runoff model, based on an enhanced distributed TOPMODEL structure, is linked to the SVAT-model in order to provide a hydrological model covering the water-cycle at the basin scale. The model is driven with meteorological data taken from regular climatic stations of the German Weather Service. The necessary soil and plant parameters for the SVAT model were either measured in the testsite or taken from literature. The topographical parameters for the runoff model were derived from detailed digital terrain analysis. The major investigative goals of the study combine the understandig and application of basin inherent physical processes within a GIS based model framework such as the spatial distribution and temporal evolution of evapotranspiration and runoff patterns. Remotely sensed data, such as airborne SAR-interferometry and imaging spectrometry are involved in improving the actuality and accuracy of the parameters in use.

SPECTRAL AND CROSS-SPECTRAL ANALYSIS OF THREE HYDROLOGICAL SYSTEMS

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Three agricultural catchments of about 5 km² located in France were studied using spectral and cross-spectral analysis of nitrate (NO_3) concentration in streamflow and discharge time series. The objective was to identify a transfer model and to evaluate an average residence time for water and nitrate for each catchment. The simple spectral analysis of NO_3 concentration revealed a unique and strong periodicity of one year for all catchments. The NO_3 concentration time series are always well correlated with discharge. However the time lag between the two time series is different for each catchment. This differentiation suggests specific hydrological controls of NO_3 exportation for each site. Either NO_3 is exported as soon as streamflow increases or exportation is delayed in comparaison of streamflow. For each catchment, we have also established the frequency response function (FRF) by the cross-spectral method between estimated NO_3 input and observed NO_3 output. By comparing the estimated FRF and FRF of theoretical transfer model, we have determined the mean residence time of NO_3. These residence times for NO_3, varying from 40 days to almost one year, are discussed in regard of field data and catchment description. This study shows that spectral and cross-spectral analysis are valuable and simple descriptive methods to get physical interpretation of water quality control in hydrological systems.

Modeling the Hydrological Patterns within a Hydrological-geochemistry Framework

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Using a physically-based topo-hydrological model, TOPMODEL, we investigated whether it is a sufficiently reliable conceptual tool to represent stormflow generation processes. The efficiency of TOPMODEL to represent internal hydrological processes within the basin was examined through confrontation of internal state variable predicted by TOPMODEL with tensiometer meausurements.
Having acknowledged the TOPMODEL modeling concept for the given catchment, to achieve a sound understanding of streamflow generation processes, we combined hydrological and hydrochemical methods within the TOPMODEL modeling framework in order to take into account both the hydrological and hydrochemical fluxes (chloride, potassium).
The proposed model was developed using the 'process' end-members - perched water table, recharge soil component and overland flow. Unlike the geochemical approach, the chemical signatures of these end-members were rather linked to the runoff generation processes than to the depths of origin. Beside the validation of TOPMODEL predictions of moisture status of the studied basin across the stormflow event, this study is intended to address the need for reconciling field results from a combined hydrological-geochemical approach.

THROUGHFLOW VARIABILITY IN A SHALLOW FOREST SOIL ON A GLACIATED HILLSLOPE: IMPLICATIONS FOR MODELLING

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Many models of catchment hydrology incorporate the assumption that hillslope flow paths can be inferred from surface topography, i.e., that flow paths cross elevation contours at right angles. While this assumption provides computational efficiency, it has been brought into question by recent studies which have emphasized the role of bedrock topography (e.g. J.J. McDonnell, 1997, J. Hydrol. (N.Z.) 36:97-100). The present research investigated the controls on the pathways followed by throughflow in a forest soil underlain by relatively impermeable basal till. Throughflow was collected in a set of 9 troughs approximately 1-2 m in width at a road cut which exposed both the soil and underlying till, as well as for a 50-m-wide hillslope segment which included the trough outflow. A network of 37 piezometers was installed upslope of the troughs to determine saturated zone thickness and hydraulic gradients. Measurements were made throughout several storms. The results indicate that flow paths may not be reliably predicted from either surface or bedrock/till topography in macroporous forest soils, particularly at the small plot scale, due to lateral shunting of flow in macropores. Further research needs to address the density, orientation and connectivity of macropore systems, and whether these effects can be parameterized for modelling purposes.

A CONCEPTUAL 10 DAYS WATER BALANCE MODEL WITH STEP WISE PARAMETER OPTIMZATION.

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Most of lumped Conceptual rainfall runoff models attempt to represent hydrological processes by mathematical equations and multiple layers of storages. These equations are sometimes over parameterized and moreover high correlation between parameters hinders identification of significance of a parameter. In this study a parsimonious lumped conceptual rainfall-runoff model for 10 days time step is described and among the parameters describing the model the base flow parameter is obtained by hydrograph analysis. The model structure consists of two interconnected layers of storages upper soil moisture and Groundwater storage. The upper storage is augmented by rainfall (infiltration) and depleted by evapotranspiration, inter-flow, and percolation to the underlying ground water storage. The groundwater storage is augmented by percolation and depleted by base flow. The link between the two layers and flow components generation are represented by fairly simple equations and water balance at a catchment scale. This model suit specially regions where two seasons rainy and dry seasons are easily identified to obtain the base flow parameter through hydrograph analysis. The model is applied to two semi-arid catchmenets, Awash (Ethiopia) and Miwmbashi (Zambia).

ON THE USE OF THE DIFFUSIVE WAVE MODEL TO IDENTIFY GEOMORPHOLOGIC TRANSFER FUNCTION FROM DIGITAL ELEVATION MODELS

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Recently, several attempts have been made to relate the hydrological response of a catchment to its morphologic features. The aim of this paper is to present a methodology to automatically identify the transfer function, using digital elevation models for applications in distributed hydrological modelling. The transfer function proposed herein is based on the Hayami approximation solution of the diffusive wave equation. Digital elevation models were used to extract channel network and subdivide the basin into subcatchments. Each subcatchment produces, at its own outlet an impulse response which is routed to the outlet of the whole catchment using the diffusive wave model described by two parameters, celerity and diffusivity functions of geometrical characteristics of the channel network. First, a geomorphologic unit hydrograph obtained by routing an homogeneous effective rainfall was compared to the unit hydrograph identified by a lumped model scheme then the distributed model was applied to take into account the spatial variability of effective rainfall in the catchment. Results show that this new method seems to be adapted for distributed hydrological modelling; it enables to identify a transfer function response of each hydrological unit, here subcatchments, and then to simulate the contribution of each unit to the hydrograph at the outlet.

LONG-TERM STOCHASTIC PREDICTION OF RUNOFF

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The contribution deals with a verification of the possibility of the long-term annual runoff prediction in the Danube (at Bratislava), the Váh, and the Labe (at Děčín) rivers using the classical time series analysis and stochastic Box-Jenkins models. The stationarity, homogeneity, trend, as well as periodicity of annual discharge series (95 to 145-annual data series) were studied. In every considered river the significant 3.6 (±0.1)-years period was found. In the upper Váh river's basin this period is manifested by substantial changes in runoff regime seven yearly (seven dry years followed by seven wet ones). Using spectral analysis, next periods (app. 2.4-; 4.2-; 5-; 10-; 13-; 14.4-; and 31- years) were identified The decrease of monthly runoff was satisfied at all considered cross-sections during the last 15 years. To illustrate the results of the modelling, the seasonal integrated mixed model SARIMA(5,0,0) $x(5,0,1)_L$ was applied in the studied rivers.

HYDROLOGICAL RESPONSE OF A SMALL CATCHMENT IN SEMIARID ENVIRONMENTS (SW, SPAIN) AND MODEL APPLICATIONS

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Hydrological behaviour is studied in a small experimental catchment (35,4 ha) situated in areas of open evergreen woodland under silvo-pastoral landuse in Spain. The hydrological response of the study catchment is complex because of the difficulty of delimiting the role of intervening factors. The results obtained demonstrate the essential function of valley bottoms filled with sediments as "water storage" and "water transmitter" in liquid and gaseous conditions. Runoff coefficients on hillslopes are higher than at the catchment scale, indicating that runoff is reinfiltrated at valley bottoms. Frequently, slope overland flow is not connected to the principal channel. Depending of the retention capacity of valley bottoms in relation with soil moisture, two runoff models have been observed: Hortonian and saturation overland flow. During the study period channel flow was measured at the catchment outlet on average 11 times per year. The most common runoff hydrograph is characterized by a very fast flood which decreases quickly. Annual runoff coefficients varied between 1 % and 15,2 %. It was intended to apply the Topmodel with data from the Guadalperalón catchment. The principal problem encountered is that channel flow is ephemeral and continuous baseflow does not exist. Consequently, it is neccessary to design a model which considers the reinfiltration mechanism of slope runoff into the valley bottoms, in order to model the hydrological response of small catchments in semiarid environments.

Nesting localized models and data within catchment models and data.

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A distinction is made between 'general' catchment models and data and localized 'process' models and data. A high resolution, 'characteristic' patch model is constructed that depicts all the local features that directly influence flow generation. In the case of the Vallcebre catchments within the VAHMPIRE project, this includes man made terraces, ditches and the variation of soil depth across the terraces. The localized patch model is used to redistribute moisture within the terrace. The predicted status of the water table and soil moisture deficit can then be tested against the independent measurements (i.e. piezometers and TDR). The catchment models are constructed from and tested against catchment data (using a DTM and a streamflow hydrograph). The catchment models, in this case TOPMODEL (20 m resolution) and SHETRAN (100 m resolution), can reproduce hydrographs well, but cannot represent the localized sub-grid scale processes. The boundary conditions and average moisture conditions within the localized model are set by the catchment model for any location and any timestep. Thus, there is a link between the local 'processes' of the high resolution model and the 'general' processes of the catchment model. In this study a simple multiple bucket terrace model is nested within TOPMODEL and a 1m resolution version of SHETRAN is nested within a 100m SHETRAN model.

A genetic algorithm for multi-criteria calibration of conceptual rainfall-runoff models

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Calibration against more than one output variable of a model is of importance for reliable simulation of internal processes. However multi-criteria calibration is not straightforward, as different goodness-of-fit measures have to be optimised. Usually, the final parameter set is a compromise between those sets obtained by the calibrations looking only at one variable. The way different goodness-of-fit measures are combined must depend on the best values that could be obtained with separate calibrations, and on the relative importance of correct simulations of the different variables. In this study a multi-criteria, genetic algorithm was used for the calibration of conceptual rainfall-runoff models simultaneously to both observed runoff and groundwater levels. Two different models were used, TOPMODEL for the simulation of a till hillslope, and the HBV model for a 13 km^2 basin partly consisting of a large esker. Including groundwater data in the calibration procedure aimed to reduce parameter uncertainty, as well as to explore the ability of these models to simulate both groundwater dynamics and runoff.

SOIL WATER DYNAMICS IN A TERRACED SYSTEM

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According to the VAHMPIRE project philosophy, catchment scale modelling has to be sensitive to the behaviour of smaller scale units for simulating properly the internal functioning of the catchment.
From previous field studies, terraced structure is known to play an important role on the hydrological response of the Vallcebre catchments. Nevertheless, the water dynamics within the terraced system can vary significantly depending mainly on soil characteristics.
In order to assess this water dynamics, two different terraces have been monitored (water content, soil matric potential, water table level and evapotranspirative demand).
Results obtained up to date evidence relevant differences in soil water dynamics between the two terraces, that induce two different saturation mechanisms. On one hand a "from below saturation mechanism as the water table rises and on the other hand a "saturation from above mechanism due to the low upper soils hydraulic conductivity.

Multiscale calibration and validation of a conceptual rainfall-runoff model

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Model calibration and validation usually is limited to comparing streamflows at the basin outlet. In this study, however, observed discharge from subbasins was used for internal validation and calibration on different scales. A conceptual rainfall-runoff model, a modification of the HBV model, was applied to nested basins of different sizes (257, 39.8, 15.2 and 0.093 km^2) located in the Black Forest in south-west Germany. The first step was to calibrate the model to the entire basin using only streamflow at the outlet and to use the runoff series from the subbasins for validation. In the second step these data were included already in the calibration procedure. Furthermore, for comparison the model was calibrated to each subbasin separately and optimised parameter values were related to the size and other properties of the basins. The agreement between measured and observed streamflow for the subbasins increased when the additional data was included into the calibration. However, it was difficult to obtain as good fits as those achieved by applying the model to each subbasin separately.

Groundwater dynamics in conceptual rainfall-runoff models - looking for more realistic concepts

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In conceptual rainfall-runoff models groundwater dynamics are represented by internal state variables. In most conceptual models an unambiguous, monotonic function between the groundwater levels and runoff is used. By this, it is assumed that the relation between groundwater levels and runoff can be described as a succession of steady state conditions. Consequently, the simulated rise and fall in groundwater levels always follow the dynamics of runoff. This assumption was studied with a geostatistical analysis of detailed groundwater level data in a Swedish till catchment. Groundwater levels in an area close to the stream followed the dynamics of the runoff while this correlation dropped off markedly further than ca 60 meter from the stream. However, there still was a high correlation between levels at similar distances from the stream. Based on these results, more realistic model concepts were proposed to capture the spatially varying groundwater dynamics. The catchment was subdivided into areas close to the stream and more distant areas, where groundwater levels were simulated that do not always to follow the runoff dynamics.

A PHYSICS BASED STORAGE-DISCHARGE FUNCTION FOR MODELLING GROUNDWATER DISCHARGE

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In many lumped catchment scale rainfall runoff models an aquifer is represented as a reservoir and groundwater discharge is determined by a single valued function of storage in the reservoir. One physics based approach to determining this storage-discharge function leads to what is often called a 'quasi-steady state' model and stems from the assumption that the dynamics of the saturated zone can be approximated by successive steady state representations (e.g. TOPMODEL). It is demonstrated here that the errors associated with this assumption are, in many cases, large and consequently a storage-discharge function which does not rely on this assumption is suggested.

A storage-discharge function is constructed for the saturated region of a hillslope based on steady state solutions of the Boussinesq equation for a range of recharge rates. This is used in conjunction with a groundwater reservoir to produce a 'quasi-steady state' model. The discharge simulated by this model for time varying recharge series is compared to that produced by a numerical solution of the Boussinesq equation. For many recharge series the 'quasi-steady state' model performs poorly in comparison. A modification to the storage-discharge relationship based upon a semi-analytic solution to the Boussinesq equation is derived which when used in conjunction with a groundwater reservoir can reproduce the discharge simulated by the finite difference model.

INTEGRATED NUMERICAL MODELING OF THE RATTLESNAKE CREEK BASIN IN KANSAS, USA.

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A comprehensive watershed-scale computer model was developed for studying the long-term hydrology of the Rattlesnake Creek Basin in South-Central Kansas. A surface flow model (SWAT) was linked with a groundwater model (MODFLOW) to obtain SWATMOD, a model that is capable of representing stream-aquifer interaction. The hydrologic response unit concept was implemented to combine the two models and represent the spatial variability within the basin. An important goal of this model was to simulate the effects of changes in water rights and agricultural land uses on the stream-aquifer response. A combination of trial-and-error and inverse modeling techniques was employed to calibrate the model based on measured groundwater levels, streamflows, and reported irrigation amounts. The paper will present model results for a 40-year historical period, followed by a 40-year prediction period during which many alternative scenarios were evaluated. The utility of such models for managing water rights over basins with water shortage will be discussed.

INVERSE PROBLEM FORMULATION FOR SPATIALLY DISTRIBUTED RIVER BASIN MODEL CALIBRATION USING THE ADJOINT METHOD

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Deterministic representation of distributed hydrologic processes requires calibration of many parameters but with only limited observations. Identification of optimal parameters that minimize a cost function composed of observed and simulated river basin discharges poses an inverse problem. The spatial pattern of parameters affecting infiltration or hydraulic roughness preconditions the search for optimal calibration parameters. The inverse model formed from the linear tangential and adjoint models allows computation of optimal calibration parameters and model sensitivity. Characteristics of the cost function surface determine whether the problem is ill-conditioned and if non-unique sets of optimal parameters exist.

INFLUENCE OF CHANNEL LOSSES ON SPATIALLY DISTRIBUTED RAINFALL-RUNOFF SIMULATION IN A SMALL ENDOREIC CATCHMENT IN THE SAHEL REGION, NIGER, AFRICA

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Local effects of climatic change impact the hydrologic cycle and resulting water resources. The recent drought in the African Sahel, persisting since 1968, emphasizes the vulnerability of water resources to climatic variations in this semi-arid environment. A GIS-based distributed hydrologic model is coupled with hydraulic and infiltration parameters derived from a remotely sensed surface condition map. The observed variance and volume draining to a pool from a 2.1 km^2 endoreic basin in an arid Sahelian environment was simulated for four rainy seasons. Runoff production, transfer, and loss mechanisms are tightly coupled using a finite element in space and finite difference in time solution of the kinematic wave equations. Drainage structures comprised of an assumed infiltrating channel network were calibrated and validated. Runoff volume was found to be very sensitive to parameters governing 1) runoff production from crusted soils, and 2) channel losses. Sensitivity of runoff volume variance to channel losses and soil crust infiltration rates will be presented.

Hydrological modeling to assess the consequences of forest management scenarios on snow accumulation, melt, and peak flows in interior British Columbia.

Whitaker, A.C., Alila, Y., Calvert, P. and Toews, D.

The Distributed-Hydrology-Soil-Vegetation-Model is calibrated to the forested Redfish Creek watershed in the Kootenay Mountains of southeastern British Columbia using internal catchment processes. The 26 km2 basin ranges between 1000 m and 2200 m in elevation, and the contribution of snow melt to peak flows is very important. The objective of the modeling is to simulate the effect of forest harvest scenarios on hydrological processes, and the resultant timing and magnitude of peak flows. Fully-distributed modeling is required to enable realistic simulation of forest management scenarios who's distribution in space and time is complex. Changes in the forest cover which alter snow accumulation patterns and melt rates can be simulated by the detailed snow and vegetation components of the model. Input data include a DEM, precipitation, temperature, relative humidity, wind, radiation, and detailed soil and vegetation characteristics. Aerial photography of snow coverage and snow course data were used to evaluate the performance of the snow melt routine. Internal tributary discharges were used to ensure the model was simulating streamflow generation at the sub-basin as well as basin scale. Five years of data are used to calibrate and validate the model. The next stage in the project is to simulate the effects of various forest harvest scenarios on long term runoff and peak flows.

NP1 Scaling, multifractals and nonlinear variability in geophysics

Convener: Schertzer, D.
Co-Convener: Lovejoy, S.M.

02 Scaling, multifractals and nonlinearity in hydrology (co-sponsored by HS)

Convener: Onof, C.
Co-Conveners: Olsson, J.; Veneziano, D.

MULTISCALING PROPERTIES OF THE THREE DIMENSIONAL SPATIAL DISTRIBUTIONS OF RAIN AND SNOW IN 10 M^3

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High space/time resolution radar rain data reveal multiscaling behaviour down to the resolution scale of a radar pulse volume. If this behaviour continues at sub-pulse volume scales, it will lead to large systematic biases in radar estimates of rain. However, a smaller resolution measuring device has to be used to directly test the small scale behaviour of the spatial distribution of hydrometeors. Stereo photography is used to detect up to 10^5 rain drops or snow flakes in a volume $\approx 10\ m^3$. The hydrometeors are lighted by two powerful xenon flashes (50 µs, 2000J). Three motorized Hasselblad cameras and stereoscopic reconstruction algorithms provide accurate estimates of their size and position. Multifractal analyses relating to the field of liquid water content (for rain drops) and equivalent liquid water content (for snowflakes and ice crystals) are performed and the implications for cloud physics, radar measurements of rain and millimeter wave telecommunication networks are discussed.

NONLINEAR EFFECTS ON THE TEMPORAL EVOLUTION OF FLUVIAL DISCHARGE : CASE OF THE OUBANGUI RIVER

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The daily Oubangui river discharge, measured during 59 years, shows a strong one-year cycle, with irregular variations along the time. Our goal is to determine the physical nature of theses modulations (stochastic or chaotic process). Although the autocorrelation time τ is about 3 months, and despite the relative shortness of the time serie (22,220 points), the Grassberger and Proccacia method can be adapted and applied to this time serie. For different pseudo-dimensions p, a pseudo-attractor can be constructed with points of coordinates $(Q(t_i),Q(t_{i+\tau}),...Q(t_{i+(p-1)\tau})$ and the correlation function C(r) is computed, where r is the pseudo-distance. The slope of the plot ln r vs ln C(r) is estimated and converges to a value near 7.5. This implies that the Oubangui river discharge evolution depends on a deterministic dynamical system, with 8 degrees of freedom. Other data analysis methods, like Poincaré sections and Lyapounov exponents may be used to confirm and sharpen this result.
Examination of the relationship between mean precipitations, measured in different stations, mean runoff and bassin geomorphologic characteristics may provide insight into the underlying physical processes influencing the river discharge evolution.

RELATIONSHIP BETWEEN MULTIFRACTAL ANALYSIS OF RAINFALL TIME SERIES AND SPATIAL RAINFALL DATA

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Better description and modelling of spatial rainfall is needed for hydrological applications (eg GCMs and simulations for distributed modelling). One of the best measurements of spatial rainfall fields is from radar. This typically renders in the order of 100 x 100 pixels for each single radar snapshot. This data is too limited for accurate enough estimation of multifractal parameters to distinguish different storm types (which is essential for GCM application).
One technique that we are exploring is using theoretical results to infer spatial multifractal characteristics from temporal ones. Under certain conditions we may regard temporal readings at a fixed site of a moving system as corresponding to an instantaneous section of the spatial field. This allows application of some recent rigorous work that relates multifractal characteristics of sections or "slices" of measures to multifractal characteristics of the measures themselves.

ELECTRICAL ANALOGY OF FRACTAL HYDRODYNAMICAL DISPERSION

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Determination of basic hydrodynamical parameters for pollutant transport in the subsurface area. Mathematical modeling of the hydrodynamical dispersion, with help of random network of tubes with percolation disorder. For each bond of the system, the tracer motion is governed by a convection-diffusion equation, with the drift term accounting for the local bond velocity. This represents an extension of random walks in disordered media to the important case of finite macroscopic flow rates. There is a Poiseuille flow in the tubes, so that the fluid flow problem isomorphic to the current flow in random resistor network. The analogy implies the correspondences: node voltages equivalent to node pressures and link currents equivalent to link fluxes. Based on this analogy a laboratorial electric modell developed to investigate the fractal characteristics of hydrodynamical dispersion. Elaborating of 168 laboratorial experiments changing the transformed electrical properties modeling of hydraulical and geotechnical parameters. Identifying of the dispersion front. Receiving the set of fractal dimension for the dispersion front in [1.38,1.51]

USING MULTIFRACTAL DESCRIPTION OF SPATIAL RAINFALL IN GCMS

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Global Climate Models (GCMs) typically operate on two dimensional spatial grids comprising squares of side 100km or more. The averaging of rainfall over such grid squares results in rainfall intensities that are too low and therefore an overestimation of evaporation and an underestimation of runoff. Current fixes include assuming a negative exponential distribution of rainfall intensities and an arbitrary fractional coverage depending on one of two storm types. There is mounting evidence that rainfall is multifractal and so the incorporation of a multifractal description of spatial rainfall in GCMs offers a more realistic approach to water balance calculations. The application of a multifractal parameterization scheme and a multifractal cascade model within a particular GCM are discussed. Preliminary results using the UK Meteorological Office's GCM SVAT model (Soil-Vegetation-Atmosphere transfer) make comparisons between all the above approaches.

ON FRACTAL CHARACTER OF SOIL SOLID PHASE SURFACE AS REVEALED BY RETENTIVITY FUNCTION

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Many properties of soils influencing their fertility as well as the behavior in ecological processes are determined by geometry of solid phase. It is particularly true for unsaturated soils composing the uppermost part of vadose zone. Usually this geometry is characterized by value of specific surface area thus leaving a lot to know about organization of this surface. In a case if soil solid phase surface exhibits fractal properties, fractal dimension and other fractal characteristics can be used in soils transport functions such as retentivity and hydraulic conductivity. Applying some model assumptions we used the relationship $dW/dh = ah^{D-4}$ (W - water content on volume basis, h - matric suction, D- fractal dimension, a-constant) to study fractal behavior of chernozem and podzolic soils. To determine h we used micropsychrometer method allowing to measure by the same technique suctions as big as 80 bar. We found solid phase surface to follow the rules of fractality ($2.39<D<2.99$) - the better the less was disturbance of a soil structure- particularly for h> 10-20 b.

MODELING OF CONTAMINANT TRANSPORT WITH HELP OF STOCHASTIC PARTICLE SIMULATION

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In this paper we investigate the simulation of hydrodynamical contaminant transport with help of stochastical particle tracking method in two and three dimensions. Using the random-walk method solving the Fokker-Planck equation with different boundary conditions, named reflecting and non-reflecting wall. The fractal nature of the porous media simulated by statistical games in possession of the fractal dimension of the investigated layer. Fractal analysis of different concentration path lines in central symmetrical case where the Pe number about 0 and for the homogen velocity field case where the Pe number 10-10000 are elaborated. Investigating the sensitivity of the fractal dimension of porous media. One of the result of this article is that the small perturbation of the initially fractal dimension of the porous media results very much changing in the path line.

ON SPACE-TIME SCALING OF CUMULATED RAINFALL FIELDS

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In the study of space-time rainfall it is particularly important to establish characteristic properties to guide both theoretical and modelling research efforts. In the present paper new observational analyses on the scaling properties of time-evolving cumulated rainfall fields are presented, and a theoretical framework for their interpretation is introduced. It is found that the time evolution of the spatial organization of a cumulated rainfall field produces characteristic scaling relationships of spatial variance vs. time. The reproduction of these relationships constitutes a basic requirement for spatial-temporal field generators in order to model important properties of real rainfall fields. It is then shown, on theoretical grounds, what properties the instantaneous rainfall intensity fields must obey in order to reproduce the experimental observations, and how the size of the observation domain affects the scaling relationships. Some current stochastic models of space-time precipitation are finally discussed and analyzed in the light of the tools introduced, to show under what circumstances the models considered give acceptable results. Furthermore, it is shown that the assumption of an exponential time correlation function, used in many current rainfall models, is not compatible with observations.

FRACTAL STRUCTURE OF LARGEST RIVERS OF CENTRAL ASIA

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Changes of climate take place in Central Asian region at present. One of possible reasons of this process is Aral Sea degradation. That is why a problem of investigation of all rivers of the region by various methods is very important. Some of the methods are used in former Soviet Union for many years others are developed unsufficiently till now. One of such methods is modeling of river network using a theory of fractals and selfsimilarity. Validation of theoretical premises of this theory was made for largest rivers of Central Asia - Naryn and Vahsh. Their run-off is not distorted powerfully by economic activity in the mountain part of their watersheds. It was shown that a structure of chosen rivers network satisfies to conditions of selfsimilarity. Some parameters selfsimilarity of the objects were evaluated. They are parameters of empirical laws of river network structure. Dependences of lengths of main on watershed areas were found. Fractal dimensions of Naryn and Vahsh River networks were evaluated.

Resultes of the investigation can be used in future for evaluation of some parameters of simulation models of a river network structure changing under an influence of various natural and anthropogenic factors. Moreover, investigation of selfsimilarity and fractals of river network can permit to compress an information for its saving.

SCALING BEHAVIOUR OF MACRODISPERSION IN A BROMIDE TRACER EXPERIMENT ON THE FIELD SCALE

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We investigate the scaling behavior of the longitudinal macrodispersivity observed in a bromide tracer experiment on the test site Krauthausen. Based on a geologic characterization, the aquifer is subdivided into three layers. For the rather heterogeneous two upper layers of fluviatile origin, we observe a power law scaling of the macrodispersity according with the scaling law discussed by Neuman (1991). In the deepest and more homogeneous layer, however, we find evidence for asymptotically Fickian behavior. Results are compared to numerical simulations and information obtained from hydrogeologic and geophysical measurements.

EMPIRICAL RELATION BETWEEN FRACTAL DIMENSION OF SUPPORT AND AVERAGE ACTIVITY FOR SPACE-TIME RAIN DISTRIBUTIONS; COMPARISON WITH A SPACE-TIME MULTIFRACTAL MODEL.

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We further discuss the two extreme hypothesis concerning the origin of zeros for rain fields: the zeros are due to (i) the rain process itself, which naturally distinguish between "dry" and "wet" areas/periods (e.g. Kadem and Chiou), and (ii) to the thresholding caused by the measuring apparatus (e.g. Lovejoy and Schertzer). An empirical relation is derived between the fractal dimension D of the *apparent* spatial set supporting rain distributions and the local rain average activity R, for different space-time rain datasets inferred from radar reflectivity signals: D varies linearly with $\log(R)$. This is in agreement with the observation of Over and Gupta (1994). However we show with the help of a space-time multifractal model (Marsan et al. 1996) that our result rather supports the second hypothesis (ii).

The success of this model to predict the observed relation is an indication that mulitplicative cascades are pertinent for the dynamical modelling of rain; they correspond to a hierarchy of rainy structures at all scales l, with typical life times t_l varying as $t_l \sim l^H$, where H is a measure of the scaling anisotropy between space and time.

FRACTAL ANALYSIS OF THE SPATIAL DISTRIBUTION OF SOURCE BASINS WITHIN THE CATCHMENT

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The most common approach to extract the channel network from Digital Elevation Models, is to specify a threshold area, S, which is the minimum area required to drain to a point within which a channel forms. It is recognized that different threshold areas will result in substantially different channel networks for the same basin. This paper studies the effects of S, which is also the scale of observation, on scaling and morphometric properties such as the number of sources and the areas of source basins and lateral basins. Twelve basins located in southern France and having their outlet in the Mediterranean sea were extensively studied. The results indicate that morphometric properties vary considerably with S, and that the spatial distribution of source basins can be considered as a fractal Sierpinski space. A simple model based on the procedure similar to the Sierpinski carpet construction is proposed to explain empirical relations between the number of source areas and the threshold, S. The model presents a new approach to estimate basin fractal properties and defines new indices to characterize the spatial distribution of first order basins. This methodology is useful for hydrologists and geomorphologists dealing with river networks and spatial patterns of various basin properties such as vegetation, soil, soil moisture and human activities.

MULTIFRACTAL ANALYSIS AND EXTREMES OF DAILY RIVER FLOW SERIES FOR BASINS FIVE TO TWO MILLION SQUARE KILOMETERS

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Daily operational river flow data from twenty river basins from the continental USA with sizes varying from 5 to $1.8X10^6 km^2$ and durations up to 80 years, were analyzed to deter mine the limits and types of scaling. Although no outer limit to the scaling was found there is a break in the scaling regime at about one to two week time period. This is in a greement with other scaling studies of rain, river flows, temperature and topography and corresponds to the "synoptic maximum" -typical life time of planetary scale disturbances. Despite the varying basin areas and series length, the estimated multifractal parame ters characterizing the infinite hierarchy of scaling exponents as well as the exponents characterizing the extreme self organized critical events, were consistent and close to the river basins from France. We used those critical exponents to theoretically determine the accumulated volume as a function of interval duration. We compared the multifractal and standard treatment of extremes showing that the multifractal treatment is quite superior.

HSB1 Water resources research

01 Water resources of international river basins

Convener: Savenije, H.H.
Co-Convener: van der Zaag, P.

MULTIFRACTAL ANALYSIS OF DAILY RAINFALL DATA

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A spectral analysis of high resolution rainfall data usually shows roughly two different regimes: a $1/f^{\beta}$ spectrum for time scales smaller than several days, and a nearly flat spectrum for scales from days to years. We focus here on the latter scales. Using wavelets for the scale degradation, we show that at these scales the rain field can be modeled with multifractals: because of the white spectrum and the non-Gaussian statistics, these can be called "white multifractals". We estimate several parameters in the universal multifractal framework, using daily rainfall data recorded in more than 100 stations in Belgium since 1951.

Using the latter parameters, we then simulate rainfall time series having the same statistics (and dynamics) as the data. This may be used as input to hydrological models.

SELF-SIMILARITY AND MULTIFRACTALITY OF RIVER PROFILES

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DEM data analysis reveals two statistical scaling properties of river profiles. Let $\Delta h(A, \Delta L)$ be the elevation difference between the section that drains area A and the section downstream at distance ΔL. A first scaling property, of the self-similar (ss) type, holds between elevation drops at different locations along the river. One finds that, with good approximation, $\Delta h(A, \Delta L) \stackrel{d}{=} r^{-H} \Delta h(rA, r^{0.5}\Delta L)$ for any $r > 0$. A second scaling property applies locally, to elevation drops from any given section to sections downstream at different distances ΔL. This second property is of the multifractal (mf) type: for any $r \geq 1$, $\Delta h(A, \Delta L) \stackrel{d}{=} W_r \Delta h(A, \Delta L/r)$, where W_r is a random variable. For the profiles we have analyzed, H is zero or slightly positive and W_r has a distribution that is close to either a log-Levy variable with low α or the product of a Bernoulli and a lognormal variable, the latter with small variance. Both mf models are consistent with a "pool-riffle" morphology. The ss and mf properties are unrelated (a river profile may be ss but not mf, or mf but not ss). In some river profiles, H or the distribution of W_r vary somewhat with contributing area A. We show that ss is a property of equilibrium topographies generated by various fluvial erosion models, whereas mf may originate from multifractality of the geologic stratification or the riverbed erosion/deposition/transport processes. Finally, we develop coupled models of the drainage area and river profile processes {A(L), h(L)} that satisfy both global self-similarity and local multifractality.

STREAM (Spatial Tools for River basins and Environment and Analysis of Management options): 'The Ganges, Brahmaputra, Meghna river basin'

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The Ganges, Brahmaputra, Meghna (GBM) catchment covers 1.8 million square kilometres of India, Nepal, Bhutan, Bangladesh and China. It is estimated that by the year 2020 the total population within the basin reaches 1 billion people. The population density varies widely over the basin from 717 per km2 in Bangladesh to 121 per km2 in Nepal. An important question related to river basin management is, given the dense- and the fast growing population, how to maintain the natural resources in the basin in order to satisfy the needs for food and water for the population. Furthermore, exogenous influences like Climate Change may cause significant changes of the balance of the hydrological cycle within the basin. The STREAM instrument (Spatial Tools for River basins and Environment and Analysis of Management options) is designed by Resource AnalysisResourceAnalysis>Main for River Basin studies with emphasis on management aspects. STREAM uses a spatial distributed water balance model for the Ganges Brahmaputra basin. This model enables the analysis of the impacts of Climate Change on the fresh water hydrology of this basin. Furthermore, land use changes are of major influence on the water availability of the GBM basin. STREAM uses Remotely Sensed data for determining land use.

TURKEY'S SOUTHEASTERN ANATOLIA PROJECT: CAUSE OF CONFLICT BETWEEN TURKEY, SYRIA AND IRAQ

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Turkey with a surface area of 780 000 km^2 and a population over 63 million, is a country with considerable water resources in a region where sufficient amount of water has never been available, and water is expected to be the key to war and peace in the future. Turkey's annual consumable water potential is 107 km^3 and the annual per capita water potential is at present 1700 m^3. Thus Turkey can not be considered "water-rich" country, and its per capita potential is nearly the same as those of its neighbours such as Iraq (2910 m^3/yr) and Syria (1420 m^3/yr). Most of the water resources of the country is in the Southeast and Eastern Black Sea region, whereas the demand is high in the Western and Central Turkey. Therefore the transfer of water between the river basins will be required in the future. South-eastern Anatolia Project (GAP) is the largest regional development project of Turkey. A total of 22 dams and 19 hydropower plants are to be constructed as components of GAP. 27350GW/yr will be produced (22% of the country's hydropower potential) and 1.7 million ha will be irrigated (19% of Turkey's economically irrigable land). The problem of the comprehensive and rational management of the integrated water and land resources of the Euphrates and the Tigris river basins can be performed by a team consisting of technical personnel from Turkey, Syria and Iraq advised by independent international experts for the rational solution of the conflict between three riparian countries.

LEGAL AND INSTITUTIONAL FRAMEWORK FOR THE MANAGEMENT OF SHARED WATER RESOURCES IN THE SADC REGION

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In the SADC region, water resources have been identified as a limiting factor to socio-economic development. The distribution of the resource and its allocation within the different sectors of population and the economy are not adequate. These problems are compounded by the threat of recurrent drought and the international nature of the most of the watercourses. SADC is committed to regional economic integration. The region has identified water as one of the key areas of cooperation by establishing the SADC Water Sector. This was further reaffirmed by the adoption of the Protocol on Shared Water Systems which lays out a legal and institutional framework for the effective management of shared water resources in the region. The current paper outlines the challenges and opportunities facing the SADC region in attaining effective management, conservation and development of water resources. The commitment of the region to regional economic integration and the role of water resources in the integration process. The paper then summarizes the development of the Protocol and how it will contribute to the aspiration of regional economic integration.

PERSPECTIVES ON RIVER BASIN MANAGEMENT

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Effective river basin management is the key to sustainable development. Within river basins land and water, surface water and groundwater and water quantity and quality water interact in many different ways. To prevent overuse and degradation, prudent management is necessary that pays due attention to these interrelations. Especially in international river basins this poses big problems as the interests of upstream and downstream countries often conflict.
This paper discusses five perspectives on international river basin management, called "natural science", "engineering", a "social optimization", "law", and "policy". To promote sustainable development, actual river basin management and applied research purported to support river basin management should integrate the different perspectives. Some concrete examples will be given. Fundamental and strategic research should recognize not only the possibilities, but also the limitations of their approach, and the different (monodisciplinary) approaches should be enriched with elements from other approaches.

EQUITABLE SHARING OF THE WATER RESOURCES OF THE ZAMBEZI RIVER BASIN

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Water is a finite resource which is unevenly distributed in time and space and which becomes progressively scarce as demand increases for its various competing uses.

Where the water resources are shared by more than one country, the sharing of this finite resource can become complex and problematic bearing in mind the different social, environmental and economic needs of each riparian country, the differing country priorities, water pricing policies and economic development levels among other differences.

This paper attempts to analyse how best the riparian states of the Zambezi River Basin may arrive at equitably and sustainably sharing the water resources of the Zambezi River Basin by proposing adoption of various principles and policies which should build on and support the project outputs of the Zambezi River Basin Action Plan Project Number 6 which is currently being implemented for the Zambezi River Basin.

SEASONAL FLUCTUATIONS OF EVAPORATION FROM A WATER SURFACE

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The solution of a lot of water management problems requires investigation of temporal series water-balance components, in particular, evaporation from a water surface. Probability regularities of evaporation fluctuation are investigated using observation data and calculated series. The analysis showed that monthly evaporation values are characterised by a higher variability that annual values, the maximum Cv values (>1) are observed in October. The two-parametric gamma-distribution can be recommended as an unconditional distribution for Cv<0.5 and three-parametric distribution with Cs=Cv for Cv>0.5. The positive correlation is observed between the succeeding months and the maximum correlation coefficients (RE>0.7) is noted in the second half of summer. Analysis of correlation between evaporation values and between their probabilities (RP) showed that RP>RE in 62% of cases. So in the first approximation, using a simple Markov chain with correlation between evaporation probabilities is recommended to describe season fluctuations of evaporation from a water surface.

TRENDS TO INTERACTIVE WATERMANAGEMENT; DEVELOPMENTS IN INTERNATIONAL MANAGEMENT OF RIVER BASINS

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The Dutch history of water policy shows different phases, in which every new historical stage adds new policy objects to the existing ones. This century a sectoral interpretation of watermanagement emerged, it was followed by the nowadays generally accepted ideas of "integrated water management". A study of new developments in water management however, leads to the conclusion that yet another concept appears. Referring to the principle that the waterpolicy agencies are in an interactive dialogue with watersystem and society system, it can be called "interactive water management". The basic elements, like interaction, water system approach, integration and sustainability are in line with several global megatrends and are generally supported by publications with global impact on issues of environment and water. Some of the elements are already put into practice, for example in the international river basins commissions for the river Rhine or in the USA-Canadian and USA-Mexican water commissions. Questions to be answered are which are these basic elements, what are the advantages and disadvantages of these new developments and what can be said about suitable institutional arrangements?

LEAST COST EMISSION REDUCTIONS IN TRANSBOUNDARY RIVER BASINS: THE CASE OF DIFFUSE EMISSIONS OF NUTRIENTS IN THE RHINE RIVER BASIN

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In an attempt to improve the ecological conditions of the Rhine, emission reduction targets have been set for different substances. For most substances the goals have been met. However, nutrient emission reductions are behind schedule.
It may be clear from intuition, and has also often been described in economic literature, that a flat reduction rate applied to all emitting sectors, though seemingly appealing for equity reasons, may not be cost-effective.
This paper explores the least cost allocation of nutrient emission reductions for the Rhine river basin, analyzing different agricultural sectors and waste water treatment plants. Special attention is paid to the regional differences in cost-efficiency.
Results show that the costs of meeting emission reduction targets can be reduced by 30% through a clever allocation of reduction targets. The compensatory payments between sectors and regions, required to guarantee a fair distribution of costs and thereby cooperation, are estimated.

THE MANAGEMENT OF EU AND SADC RIVER BASINS COMPARED

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During the conference on The Management of Shared River Basins, held in Maseru, Lesotho, in May 1997, five case studies were presented on the management of international river basins in Europe and Southern Africa: The Rhine-Meuse, the Danube, the Zambezi, the Incomati-Limpopo and the Orange. The management characteristics of these river basins are quite diverse: they are situated in entirely different climatical zones and support quite different socio-economical systems. To allow comparison, these river basins are assessed against an analytical framework which is symbolised by a classical temple which has integrated water resources management as the foundation and which rest on three supporting pillars: the political environment, the operational capacity and the institutions. In the comparison of these river basins interesting similarities and distinctions appear, which may have generic value for the management of international river basins elsewhere.

HSB1 Water resources research

02 Influence of environmental and antropogenic change on flood processes (co-sponsored by NH)

Convener: Blöschl, G.
Co-Convener: Burlando, P.

ON FLOOD PROCESSES OF THE INFERIOR SECTOR OF THE DANUBIAN RIVER

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In analysing the influence of the antropogenic change on the flood processes of the inferior sector of the Danubian River, the general schema of the impact studies was used: the generating process of changing was hydraulic structures of the inferior sector of the Danube, the direct receptor environment - the of the Danube, the transfer characteristics of the flow of water and sediments and of the river bed, the indirect changed environment - the delta and the sea coast. The hidraulic accounted structures are: the Hydroenergetique system Portile de Fier, the The consequences on the flow components (water and sediments) was revealed as well as the modification of the morphological structures of the river bed.

THE ROLE OF DESERT FLOODS IN SPREADING POLLUTION ALONG AN ALLUVIAL AQUIFER: THE NORTHERN NEGEV DESERT, ISRAEL

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Floods along arid ephemeral streams are considered as the major source of groundwater recharge into the shallow alluvial aquifer. The latter, however, is served as an intermediate sub-surface storage for deep percolation and recharge into deep regional aquifers. Contaminants accumulated in upper basin reaches, may be transferred by floods, spread along the riverbed, and may percolate into the shallow aquifer. The level of the contamination is controlled by the rate of streambed infiltration and by the hydraulic properties of the alluvial sediments. As the level of pollution is diluted downstream, the longitudinal flux along the alluvial aquifer and mixing with local water control the spatial distribution of the groundwater pollution. Antropogenic pollutants and industrial contaminants have accumulated in the upper Beer Sheva wash in the Northern Negev desert, Israel. Geomorphic structures coupled with multi-variable cluster analyses performed on dissolved chemicals and environmental isotopes in the shallow groundwater were used to discretize the alluvial aquifer into hydrological compartments. A multi-cells mixing cell model was applied to identify and to quantify sources of recharge, rates of streambed infiltration and longitudinal fluxes along the shallow alluvial aquifer. Results elaborate on the role of floods in relation to the geomorphic structure in transmitting pollution along graveled-bed aquifers.

FORESTS AND FARMLAND ABANDONED CATCHMENTS: A COMPARISON OF FLOOD PROCESSES

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Flood processes are closely linked not only to the characteristics of rainfall events but also to the main features of the catchments (slopes, plant cover, permeability of soils). To integrate all these factors, the Pyrenean Institute of Ecology has monitored two catchments in the Borau (Loma de Arnás catchment) and Aísa (San Salvador) Valleys, Central Spanish Pyrenees. Information on precipitation, air temperature, soil humidity, sediment transport and discharge has been obtained continuously since 1995. The purpose of this paper is to study the characteristics of the floods in two catchments, one occupied by abandoned fields and another by a dense forest cover. The results show the effects of forest recovering on peak flows and on time lag since the beginning of the precipitation and also allows to establish seasonal comparisons.

A DIGITAL DATA BASE OF CATCHMENT CHARACTERISTICS FOR ASSESSING ANTHROPOGENIC EFFECTS ON FLOOD PROCESSES

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Regional analyses of flood processes are greatly facilitated by a coherent data set of catchment characteristics covering the entire region with sufficient detail. We have used the digital data base of Behr (1989) as a first step. This data base covers all of Austria (totalling an area of about 90000 km^2) and consists of (a) the boundaries of 20000 natural catchments with a total of 10^6 nodes and (b) the stream network with a total of $7 \cdot 10^5$ nodes. Both pieces of information have been digitised at a 1:50000 map scale. As a second step, this data set is being combined with stream gauge locations. This gives the boundaries of about 500 gauged catchments. As a third step, these data are being combined with a digital elevation model of the region and with land-use data derived from Thematic Mapper images. This allows us to derive topographic characteristics (such as mean slope) and land-use characteristics (such as percent forested area) for all catchments in a coherent way. As a fourth step regional flood frequency data are now being examined in the light of these catchment characteristics. This is done (a) by a downward approach by deriving and regionalising statistical relationships between flood frequency characteristics and catchment characteristics, and (b) by an upward approach by derived flood frequency simulations. The latter analysis makes use of additional data such as rainfall and a regime type classification of catchments based on the seasonal variability of stream flow. Both approaches will allow us to examine the role of land-use and/or climatic forcings in the regional distribution of floods and to analyse the potential impact on flood processes of anthropogenic changes in land-use and catchment management. Preliminary results of the analyses will be presented.

Behr, O. (1989) Digitales Modell des Oberflächenentwässerungssystems von Österreich. Technical Report No 11, Institute of Hydraulics, Hydrology and Water Resources Management, Technical University of Vienna, 65pp.

HYDROLOGY AND FOREST: A MODELLING APPROACH ON THE MONT LOZERE (FRANCE)

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In the framework of the European project FOREX, the impact of forest and silvicultural practices upon extreme flows of rivers is studied on three small experimental watersheds located on the southern flank of the Mont Lozere (Massif Central, Cévennes, France) and characterised by a mountainous and Mediterranean climatic influence. Each watershed is covered by a specific type of vegetation (grassland, beech and spruce). A clearfelling has occurred on the spruce watershed followed by a slow reforestation. A lumped hydrological model able to simulate the soil moisture has been calibrated on the three watersheds by comparing simulated runoff with observed data. In order to validate the simulated soil moisture evolution, an automatic measurement site has been settled on the two forested basins. Difference between parameters values is studied in term of vegetation cover influence on hydrological processes. We analyse the parameters values evolution in parallel with vegetation cover change on the spruce watershed. The stability of the model calibrated parameters is controlled on the two other watersheds where the vegetation cover is stable during all the observation period. This modelling approach appears useful to quantify the influence of forest on water storage in soils and on losses by interception and evapotranspiration. On the other hand, the forest protection against floods, especially against the well known and spectacular Cevennol floods, is not clearly demonstrated, in agreement with previous studies.

RISK OF FLOODING AND PROBABILITY OF EXTREME FLOODS

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Risk is the potential of unwanted consequences from impending events. Risk assessment involves the conversion of consequences to a numerical loss and an often applied measure of risk is the statistically expected loss i.e. the sum of products of the losses and their corresponding probabilities. A common impression of an increase in the risk of flooding thus does not automatically imply an increase in the probability of extreme floods. Factors creating risk of flooding are analysed on the example of the Glomma River (40000km^2) in Norway in this perspective. These factors can be divided into upstream controls in headwaters and main rivers and on site characteristics of a floodplain. The influence of individual changes in land use by deforestation etc on floods in headwaters can be studied by physical approaches like derived distribution functions. However, these approaches at present have limitations when it comes to the upscaling to large basins. Synchronicity in time of floods in headwaters significantly effects the character of the downstream flooding. Empirical scaling relationships of floods with different return periods offer a better tool for analysing this synchronicity and also the effect of regulation in the main river system. The on site characteristics of a floodplain are of importance for both the probability of flooding and the cost of damage by the flooding. These characteristics include the channel properties as expressed by a stage discharge curve, the topography of the floodplain including artificial levees and embankments and the degree of economic exploitation. The contribution of the latter factor is constantly increasing causing an increasing risk of flooding.

LAND-USE CHANGES INFLUENCING STORM RUNOFF GENERATION AND THE POTENTIAL OF DECENTRALIZED FLOOD RETENTION MEASURES TO COMPENSATE FOR SUCH CHANGES – A SURVEY

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Decentralized flood retention measures are extensive measures reducing and delaying storm runoff generation throughout the whole catchment area. A reduction of storm runoff generation can be achieved by afforestation, cultivation practices preventing overland flow, or structures like hedges or balks subdividing hillslopes, for instance. These measures should be adopted in parts of the catchment with a specifically high runoff production rate. In a wider sense, numerous small measures along the channel network are called decentralized as well.

The aim of decentralized flood retention measures is to compensate for anthropogenic changes within the catchment. But so far, measurements documenting the impact of such measures at different scales are rare. In this contribution, conclusions about their potential for runoff reduction are drawn by reviewing studies focussing on the impact of urbanisation, reallocation of land, deforestation, or river regulation on runoff generation and flood runoff, respectively. This review leads to a qualitative estimation of the extent to which the flood response of a catchment can be influenced by human activities.

ON THE IMPACT OF FLOOD-CONTROL RESERVOIRS ON HYDROLOGIC RISK

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A distributed model of catchment dynamics has been used in order to evaluate the impact of flood-control reservoirs on downstream flow propagation under variable storming conditions. The catchment model calculates local contributions to infiltration excess runoff at each elemental cell by means of a time compression approximation water balance model and routes these contributions throughout a conceptual drainage network extracted from digital elevation model data via a diffusion wave routing model based on the Muskingum-Cunge method with variable parameters. Level pool routing is modeled via a fourth-order Runge-Kutta routine. The reservoir is described in terms of elevation-storage and elevation-discharge curves so that the outflow is calculated dynamically during flood events in response to the inflow hydrograph from the controlled upstream drainage area. The obtained model is applied to the approximately 840-km^2 Sieve catchment (Central Italian Appennines), where the 69×10^6-m^3 multi-purposes Bilancino reservoir controls an upstream drainage area of about 150 km^2. The impact of the Bilancino reservoir on the hydrologic risk for the downstream Sieve catchment is evaluated by comparing hydrograph peaks and times to peak at several sections along the catchment mainstream, as simulated by the model for the natural (without reservoir) and controlled (with reservoir) scenarios.

FLOW ROUTING IN LARGE RIVER BASINS

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Due to recent advances in several areas, it now appears feasible to predict discharges of water and suspended sediment at all locations in a river basin, given sufficiently-accurate topographic data for the basin and a sequence of remotely-sensed or model-derived rain field snapshots. A robust solution to this problem requires the ability to successfully perform the following tasks: (1) fast and reliable extraction of river network flow lines from available digital elevation data (which may not be "hydrologically sound"), (2) a complete, physically-based theory of downstream hydraulic geometry (which can be used in conjunction with existing gauging station data to self-consistently assign values to regions in the basin for which data is not available), (3) a robust and tested method for parameterizing flow resistance in a complex setting, and (4) a vertically-integrated numerical flow model in two space dimensions. Substantial recent progress in each of these areas will be explained, and some of the computational challenges of generating real-time forecasts with short lead times will be discussed.

Abstract

The HYDRA research programme has been established to examine the hypothesis that the sum of all human impacts in the form of land use, regulation, flood protection etc., may have increased the risk of floods. The main objectives is to extend our knowledge of the connection between natural resources and human impact in the watercourse and throughout the catchment on the one hand, and floods and flood damage on the other. The programme shall propose measures to prevent damaging floods, and to reduce flood damage in a cost effective and environmental optimal manner. The programme was established by the Norwegian Water Resources and Energy Administration in early 1996, and will terminate in 1999. The cost of the programme is NOK 17-18 million with 47 participarting scientists from about 15 Norwegian institutions. The leader of the programme is Professor Arnor Njøs.

The scientific work is performed by a number of project groups: N – "Natural resources and land use", T – "Urban areas", F – "Flood reduction, flood protection and flood management", R – "Risk analysis" and Mi – "Environmental consequences of floods and flood prevention measures". The scientific work is supported by the D – "Databases and GIS" group and the Mo – "Modelling group". The N-group is studying the effects on floods of geology, soils, forest coverage and in small catchments and. The T-group is studying the impact of floods on the urban areas within the Glomma basin. The F-group has completed a study on historical floods, and studying the effects on floods of hydropower regulation, constructing flood protection works, and the uncertainty of the forecast. The R-group conducts a study on risks of flood damage on houses and agricultural soils, and is developing methods for flood zone mapping. The Mi-group is studying environmental consequences of various measures to reduce flood damage, and will propose how environmental consequences could be included in the planning of such measures. The Mo-group is developing and testing a general model to study and quantify the total effect of human interferences in the watercourse and drainage basin.

The early phase of the programme has consisted in compiling data suitable to testing the original hypothesis. The paper will present some early results of the analyses, which will be completed by the end of 1998 by the various scientific project groups. The final modelling will be completed in the first part of 1999.

Dynamic model of the non-outletted reservoir (DMNOR) and prognosis its level of change.

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It's known fact that processes happen in the stratums between cores of the Sun and the Earth, which influence the level of the non-outletted reservoir (LNOR).However, for all those catastrophic situations there rise produce in the dynamic of reserved lakes. The heliofactors regulate the LNOR through climate, atmosphere, hydrosphere and lithosphere. The connection are watched with the change the parameters of the Sun. The change of the speed of the Earth's rotation leads to endogenic processes and the deformation processes (DP) in the crust. Dislocation of the rotation of the Earth's axis leads to same situation. In the DMNOR, the DP are regulated with the absolute level of the undeground hydrosphere. Antropogenic factors play a srecific role in DMNOR. It's possible to take into consideration the influence of antropogenic factors, as global warming occurs. Hence it follows that DMNOR consist of an established connections of systems: «the LNOR - Sun's activity», by the temperatures and dynamically parameters of the heliosphere. «The LNOR - DP of the Earth», by the Earth's rotational regime. On the example of the dynamic of the level of the Caspian Sea, connections are established in the different systems. The 22-90 year cycles are observed in the trend changes. DMNOR is made up of global, regional and the technical change in many stratums between the Sun and the Earth. And real rise it fall of the water level needs to be of monitored in stratums between the Sun and the Earth.

MODELLING CLIMATE AND MAN-INDUCED EFFECTS FOR FLOOD RISK ASSESSMENTS: OPEN PROBLEMS AND RESEARCH PERSPECTIVES

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In this decade the repeated flood disasters that occurred in urban areas of Europe with high damage and loss of human lives have emphasized climate and man-induced effects on floods as a fundamental research commitment with major implications in both hydrological science and engineering. Current flood risk analysis methods require to be improved to account for these effects, and some of deterministic and stochastic models presently used for prediction of design floods must be revised under this view. New insights and benefits could be obtained from the increase of knowledge on hydrological processes that has been achieved in the past two decades, resulting in the improvement of the physical basis of hydrological models. However, a number of problems and difficulties still remain unsolved, when using physically based models to approach the assessment of flood risk and the design of engineering works under the impact of climate and human activities. Some examples are presented and discussed addressing open scientific issues that might be properly investigated by jointly considering the scientific advances and the engineering requirements of flood related problems.

DETECTION OF CYCLICAL OSCILLATIONS OF TEMPORAL SERIE OF WATER FLOU AND CONCENTRATION OF NUTRIENT MATTERS IN WATERS OF THE DNEPR RIVER BASIN

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By means of a method of sliding average , research of temporal series of water flou and concentration of nutrient matters of 23 rivers of the Dnepr river basin was made during the long-term period of 1945-1990.

The analysis of the graphs of values of water flou has proved the presence of cyclical oscillations of average annual water flou wich are seen in sequential alternation of phases of fall and rise, i.e. lowand high water phases (terms). During the mentioned period of time it is possible to select 2 full cycles of change of the water flou: 1) 1956-59 - 1969-71; 2) 1971 - 1981.

The cycles with such periods of passing and duration, respectively 12-16 and 11 years respectively, are characteristic of majority of the rivers of the basin. Is detected as of concentration of nutrient matters (NO_2^-, NO_3^-, PO_4^{3-}) cyclical ostillations. It is discovered that phases of magnification and diminution of concentration of substances and somilar phases of water flou are simultaneous. A conclusion about possible cyclical character of the processes of anthropogenic eutrophication of surface water is made.

HSB7 Water Resource Research

03 Remote sensing and GIS in Hydrology

PROBLEMS AT SOIL BORNE REMOTE SENSING USE UNDER HUNGARIAN CHANGEABLE WEATHER

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Investigations on possible use of IR technique for irrigation timing under different growing season's weather were carried out at Keszthely, Hungary. To test validation of canopy temperature based crop water stress index (CWSI) concept three watering levels were applied: rainfed conditions, lysimeters, /or traditional irrigation timing (available soil moisture content), and irrigation scheduling according to the limit level of CWSI. In arid summers the application of canopy temperature -on assessing actual plant-water status- served the same results as usage of traditional irrigation timing methods. The only difference was decreased amount of applied irrigation water. During humid summers, increased amount of rainfall was associated with other changes in meteorological elements: frequency of days with wind events grew significantly together with relative humidity content of the air. As a result of convective heating the basis of CWSI, the canopy temperature decreased drastically, independentely on existing plant-water relation. Analysing the influence of convective heating on canopy temperature their relation has to be taken into account when wind speed exceeds 1-2 m/sec above the canopies. The second problem in humid seasons is narrowing of applied parts of the „baselines" resulting from decrease of the air vapor pressure deficit. These changes paid our attention on careful handling of remote sensing data (CWSI) when humid growing seasons exist.

A UNIFIED RAINFALL CLIMATOLOGY OF THE MEDITERRANEAN OBTAINED BY SATELLITE AND SURFACE DATA

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Rainfall climatologies of the Mediterranean suffer from the lack of information as in many other regions of the world. The availability of rainfall estimates over the sea areas, as obtained by suitable interpretation of passive microwave imagery, provides new perspectives in the analysis of rainfall climatology and a chance to attain a much more in-depth investigation of the processes involved than has been possible hitherto by means of traditional rainfall monitoring over the land areas alone. The EU-ACROSS project was developed under the framework of the DGXII-AVICENNE Initiative by a consortium of Universities and Research Bodies from Italy, UK, Turkey, Jordan and Syria, with the aim of producing a unified climatology of rainfall over the Mediterranean region, remotely sensed over sea and ground observed over land. An overview of the project results is provided in this paper with particular reference to the integration process of the two main sources of data, together with some discussion of the results in terms of the rain and rain frequency differences that were encountered between the ground based and remotely sensed data sets. Interpretation of these differences are sought in terms of the typical geomorphological and climatological features of the Mediterranean.

THE USE OF A NATIONAL GIS DATABASE FOR SOIL EROSION MODELLING IN THE U.K. USING A MINIMUM INFORMATION REQUIREMENT APPROACH.

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The need for accurate and widely applicable data pertaining to the national soil erosion picture in the UK is recognised. At the policy scale, guidance is required to aid decision making and prevent the long-term loss of topsoil which is often overlooked by the individual farmer in the short-term. A national database has been compiled within GIS ARCVIEW containing all the relevant data to model soil erosion on both UK farmland and upland areas. Parameters required by the soil erosion model WEPP (Water Erosion Prediction Project) are derived through the ARCVIEW database to run a Minimum Information Requirement version of the model, at the national scale. ARCVIEW is used to visualise potential areas of topsoil degradation and erosion, due to possible future climatic scenarios, management practices or hydrological regimes. This work is part of an attempt to further the use of GIS in tandem with state of the art hydrological modelling techniques.

Determination of runoff parameters in northern Algeria using remote sensing data and GIS

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This paper describes the possibility of using remote sensing data in order to obtain the information necessary to apply a hydrological runoff model. Remote sensing techniques have rapidly developed these last years and offer a practicable way of limiting ground work to previously identified classes with the same physical properties. The established classification does not correspond to an usual pedological soil map but does reflect the physical soil properties, which influence the infiltration patterns (or runoff generation). Furthermore it is possible to obtain information about the antecedent soil moisture distribution by applying a principle component analysis to the satellite images. These detailed information is coherent for the whole coverage of the satellite image which allows the modelling of even large basins in a detailed way. No traditional field method is capable of furnishing a similar amount of detailed simultaneous data.
This modelling technique was used within a project of the Algerian-German technical co-operation dealing with the introduction of new technologies to the Algerian Hydraulic Resources Administration. On an example in Northern Algeria the application of this combined modelling technique is shown.

DERIVING PEDO-HYDROLOGICAL CHARACTERISTICS OF A HUMID, TROPICAL CATCHMENT (SOUTH EASTERN NIGERIA) BY SOIL-LANDSCAPE MODELLING

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This paper outlines the strategy deployed for deriving the pedo-hydrological characteristics of a case-study (500 km^2) humid, tropical catchment in south eastern Nigeria. The starting point for this research was the availability of a dated (1961) but good quality 1:50,000 topographic map; the aerial photographs (not equally well preserved) used to make the topographic maps; and a geological map (1:250000). The contour lines of the topographic map were digitised, and use was made of the TIN module of ARC/INFO to interpolate the contours, and then set up a gridded DTM. The geological boundary units were digitised and overlayed onto the DTM, to stratify the area according to parent material. By adopting the hypothesis that soil toposequences develop in response to the way water moves through and over the landscape, soil pedons were surveyed and sampled along representative transects. Statistical models were developed using the relationships between terrain attributes and soil attributes, to predict spatial patterns of pedo-hydrological characteristics across the area.

ESTIMATION OF TRANSPIRATION FROM SPARSE VEGETATION

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In the Sahel, water availability is occasionally low causing the transpiration rate, or the stomatal conductance, to be an important parpameter in crop growth modelling. In this region, the vegetation cover is furthermore very sparse and the signals recorded by the satellites depict the conditions from both the soil and the vegetation. Often, the soil evaporation is inhibited by low hydraulic conductivity in the top soil layer, whereas the leaf transpiration rate may be high stressing the need for a two-source analysis approach. It is shown that the relationship between surface temperature (Ts) and vegetation index (VI) estimated on basis of high resolution satellite data is useful for evaluation of the separate temperatures of soil and vegetation. The processes controlling the canopy fluxes vary as symbolized by the Ω coefficient (Jarvis & McNaughton 1986), which can be related to $\delta Ts/\delta VI$. Three typical Sahelian surface types characterize the study area; a) tiger bush, b) savannah bushes and c) millet fields. The Ω factor is typically high for millet indicating low stomatal control, while the two other dominating surface types are characterized by low Ω. For millet, an important energy source is provided by a sensible heat influx to the leaves causing transpiration to be linearly related to LAI times the vapour pressure difference between the leaf surface and the bulk air. Therefore, millet transpiration can be estimated on basis of satellite data knowing only the atmospheric vapour pressure. The transpiration from the bushed areas is discussed on basis of the spectral signatures on 3 days.

LANDSAT TM AS A TOOL FOR MAPPING THE LAND COVER OF A HUMID TROPICAL CATCHMENT

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This poster outlines the method adopted for mapping the land cover characteristics of a case-study (500 km^2) humid, tropical catchment in south eastern Nigeria. An unsupervised and a supervised classification is carried out to obtain land cover classes for the area. Ground truthing and detailed aerial photographs (1:6000) of a small section of the catchment are used to improve the catchment wide classification scheme, which can be used to map effective rainfall as an input for distributed hydrological modelling.

WATER RESOURCES OF THE RUSSIAN ARCTIC ONSHORES (RIVER MOUTHS AND PERMAFROST): EXPERIENCE OF X,L,P,VHF SAR-DIAGNOSTIC.

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X,L radar systems apply for the coastal zones observing successfully (Alomaz,Seasat, ERS projects). L,P,and VHF bands have been added to X band provide thematic decoding frontal zones, mezoscale whirlwinds (eddies), mouth river water lines, shallow lines and others. There are multifrequency aircraft (Tupolev 134) radar technical values and some X-.L-,P-.VHF-images of Barents and White Seas coastal in presentation. Examples of SAR water catchment imagesand permafrost patches on the water catchment are demonstrate.

ON THE USE OF MULTISENSOR DATA FOR RECONSTRUCTION OF THE RAINFALL FIELD AT DIFFERENT SCALES

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Wide use of the available remote sensing devices has been made in recent years in order to increase the actual reliability of rainfall predictions to be used in flood forecasting applications. Various satellite sensors and radar devices are often integrated with traditional rain gauge networks so as to obtain cross-fertilised estimates of the observed rainfall fields. Quite relevant problems of scale are involved in this exercise (and seldom investigated) though validation of rainfall data obtained as an average value at some spatial and temporal scales is yet performed by means of point values obtained at the gauge site. The use of multisensor data requires that suitable algorithms are developed to produce data at coherent space and time scales. In this paper data from the Meteosat geostationary platform are used, together with traditional rain gauges, for reconstruction of the rainfall field at different scales on the Italian territory. Quantitative and qualitative information is used and a suitable methodology is proposed for data integration. The objective is that of reading the large scale field structure from satellite data, while calibration of the numerical syntheses at small scales is obtained by ground based sensors. The predictive content of remote sensing is therefore transferred at the ground so as to forecast the small scale evolution of the field, where the resolution scales must be coherent with the needs of the hydrological modelling of the ground effects.

ASSESSMENT OF SOIL HUMIDITY AND SEDIMENT SOURCES IN SMALL CATCHMENTS USING GIS

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One of the most important purposes of the soil erosion studies is to identify sediment sources in order to decide the most adequate strategies for land reclamation. The eroded areas can occupy most of a catchment, but the really sediment contributing areas may be small surfaces. The problem is how to detect easily these contributing areas in catchments of hundreds or thousands of hectares. One possible way is to work initially with small catchments in wich detailed studies on sediment sources and soil humidity are coupled with topography. For that, geomorphological mapping (including soil erosion processes and mass movements) and periodical control of soil humidity is needed. The results can be managed with a GIS, allowing a generalization, in probabilistic terms, to larger areas.

DISTRIBUTED MODELLING USING DIFFERENT ROUTING ALGORITHMS AND VALIDATION AGAINST REMOTELY SENSED DATA.

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The study presents a distributed hydrological model closely coupled to a GIS data base. The hydrological model PHASE was built for highlighting the reciprocity between vegetation and the water cycle by using remotely sensed data as input. The basic idea behind the model is that vegetation and its products function like a sponge. With a large capacity of holding and actively controlling water when in a good (moist) condition, and with a severely lowered control capacity when dried out or absent. The semi-distributed version of the model has shown robustness when transferred between different catchments in the same region. The early version did not handle partial contributing area flow or other distributed processes. In this paper different routing algorithms for fully distributed modelling are compared and related to distributed data sets of wetness and vegetation indices.

CALCULATION OF P.E.T. IN SPAIN USING GEOGRAPHICAL INFORMATION SYSTEMS

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The aim of the study that is presented, is to make the most of the applicability of both Thornthwaite's Method and the Penmann - Monteith Method. The former only requires knowledge of a small number of variables, latitude and average temperatures, which are easy to calculate and process in geographical information layers. The latter, is a more reliable method, because it takes into consideration more factors that play a part in the process. However, information regarding these other factors, is only recorded at a limited number of stations, about 100 in Spain. If both methods are applied in those stations with such complete data, it is possible to obtain a series of corrective factors that can be regionalised using the tools available in the G.I.S. Thornthwaite's Method can then be applied with the aid of the tools available in the G.I.S., and the PET results can be corrected through use of the above-mentioned corrective factor, making use of the information concerning temperatures, recorded at approximately 1,000 stations. The final result, is the average PET according to a Thornthwaite Method modified by the Penman - Monteith Method. The procedure has been completed by applying an experimental factor, which represents the influence of the vegetation cover in the PET calculations, which is obtained from an analysis of balances in the basins.

TEMPORAL SERIES OF AVHRR-NDVI IMAGERY OF IBERIA: HYDROLOGICAL SIGNIFICATE.

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Previous results have shown that temporal series of AVHRR-NDVI images can be used to provide a hierarchical partition of Iberia that is in accordance with its bioclimatic division.
Multi-temporal NDVI centroids can be interpreted in terms of temperature and water availability, with Atlantic vegetation peaking in Summer and Mediterranean vegetation peaking in early Spring because soil water depletion.
I further analyze these multi-temporal centroids in terms of temperature and water availability using soil water budget models based on climate data and soil information.
Finally, I discuss the use of remote sensing data for regional hydrological studies and for up-scaling fine resolution field data.

ESTIMATING HYDROLOGICAL PARAMETERS WITH MULTI-FREQUENCY SAR DATA

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This paper presents an overview of the results obtained from different SAR missions on various test-sites (MAC- 91, SIR-C/X-SAR in 1994, ERS-1 and JERS-1 in Italy, EMISAR in 1994 and 1995 in Sweden). Since SAR images were collected in different seasons, from spring to fall, a wide range of soil moisture and cover conditions was investigated. The measured quantities were the full polarimetric features at L- and C-bands and the backscattering coefficient $\sigma°$ at VV polarization at X band. The sensitivity of backscattering to surface roughness and soil moisture has been evaluated and compared with theoretical simulations. It has been found a fairly good correlation of backscattering to soil moisture of bare or scarcely vegetated fields both at L- and C-bands and $\theta = 23°$-$26°$ where the influence of surface roughness and vegetation cover is minimized. However, the quality of SAR images at θ close to the nadir is affected by a relatively poor spatial resolution which makes it difficult the exact identification of field borders. The correlation appreciably increases up to 90% if soil moisture is estimated, in different times, on the same area including many fields. The measurements indicate that the effect of surface roughness on backscattering is appreciable at all frequencies and polarizations taken into considerations. The highest correlation to the height standard deviation of the surface was found at L-band $\theta \sim 35°$.

LAKE LADOGA DATA BASE: A NEW VIEW ON THERMAL PROCESSES REPRESENTATION AND GENERALISATION

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Recognition and understanding of the characteristics of the temperature regime of a lake are key to successful interpretation of information on its physics, chemistry and biology. For the largest European Lake Ladoga (area 17800 sq.km, mean depth 47 m.) the database is firstly created. It includes the field measurements of water thermal characteristic and meteorological parameters for period from 1898 to 1997 years. Total data density equals about 110 points per cu. km. Various statistics were calculated for different seasons, regions and depths. It has shown there are a considerable temperature differences up to 50 m depth. The model of spring thermal zone movement is developed on the basis of the database and has verified using of the satellite IR-information. The portion of nonseasonal temperature variability in total dispersion has been estimated by the polynomial approximation.

THE HYDALP PROJECT; TOWARDS OPERATIONAL REMOTE SENSING APPLICATIONS IN SNOW HYDROLOGY

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HYDALP (Hydrology of Alpine and High Latitude Basins) is a project of the Centre for Earth Observation (CEO) Programme which is part of the Climate and Environment Programme of the EC. The project aims at the application of EO data in synergy with conventional data to improve the modelling and forecasting of daily runoff in alpine and high latitude basins. Test basins are located in the Austrian and Swiss Alps, in Scotland, and in Northern Sweden. Automatic and semi-automatic methods have been developed to derive digital snow maps from Synthetic Aperture Radar (SAR) and optical data. The runoff calculations are based on the hydrological models SRM (Snowmelt Runoff Model of Rango and Martinec) and HBV of SMHI. An integrated system for efficient use of the remote sensing products in the models is under development. Preliminary results of runoff simulations in the Austrian basin are promising. In 1999 pre-operational tests are planned to investigate the usefulness and cost-effectiveness of the remote sensing information for daily runoff forecasts.

GIS OF WATER OBJECTS OF KARELIAN ISTHMUS (NORTH-WEST OF RUSSIA)

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The base of dates was created for the first time for more than 300 lakes of Karelian Isthmus. All the morphometrical characteristics and bathimetrical maps of lakes are include in it. New dependence between the morphometrical characteristics for lakes of different types of origin were got. On the base of this information and large-scale maps the GIS for the Karelian Isthmus was created. GIS consists of all the information for morphometry of lakes and its watershed, the outflow of rivers and levels of lakes, for outflow of base lakes-rivers system Vuoksi, and also, for literature which belongs to the water object. GIS - is a multilevel system of maps and tables which are giving all the information on marked object (lake, river). GIS is constantly improving of information and by the present moment it includes the quantity of dates, which is represented in the table:

lakes with full dates on morphometry	lakes with particle dates on morphometry	lakes with dates of thermics	lakes with dates of levels	rivers	rivers with dates of outflow
>300	>1500	>20	9	>1500	15

GIS will be used for creation of models of flow and carrying and transformation admixture in water ecosystem and also for quick and comfortable representing of the necessary dates on water objects of Karelian Isthmus.

THE USE OF MULTI-LAYER REMOTELY SENSED DATA FOR ESTIMATING SURFACE HEAT FLUXES

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Remotely sensed data were used to estimate surface heat fluxes in the Monsoon 90 experiment conducted in southern Arizona in 1990. Landsat TM data were used to map the variations in surface land use and vegetation cover. These data were used in a two-source model with remotely sensed surface temperatures from an aircraft platform to the determine the fluxes. The two-source model treats the fluxes from the soil and canopy separately. The land use information and vegetation indices were used to estimate parameters in the model e.g. fractional vegetation cover was estimated from the vegetation indices. In addition measurements of the surface air temperature and wind speed were required. This approach was applied to surface temperature images for 3 days in early August 1990 (1, 4 and 9). The conditions ranged from very on August 1 to very wet on August 4 after up to 50 mm of rain fell on the watershed. The agreement with the ground flux measurements is reasonably good and better than that obtained using a single source model with a constant transfer coefficient over the watershed.

REMOTE SENSING TECHNIQUES FOR DETERMINING THE REGIONALLY VARIABLE CHARACTERISTICS OF DRAINAGE BASINS

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The image data obtained by means of aerial photographs or from satellites records proved to be valuable information sources for the analysis of the factors characterizing spatial variability, that influence and condition the water runoff in a dainage basin. The paper presents the methods used for the determination of the characteristics of the basins on local and regional scale. The established unit was the "facet" defined as a relief element, homogenous from the standpoint of factors acting upon the water runoff. The transition from the local to the regional scale may be achived by succesive integration of "facets" in elementary drainage basins. The storage and handling of data on the characteristic features of the "facets" in a drainage basin were based on a G.I.S. principle. In order to understand the hydrological processes occuring in drainage basins, it is necessary to have knowledge of the space-time variability of factors that influence water flow. By providing the user with image data (with local, regional or global covering) remote sensors contribute to a comprehensive understanding of hydrological processes taking place in drainage basins and to the transition from point to areal as well. The paper presents the methods and procedures developed by the Remote Sensing Team in the Institute of Meteorology and Hydrology, Romania, for the purpose of determining the spatially variable factors influencing and conditioning water flow.

COMBINING SATELLITE, GROUND-BASED AND ASSIMILATED DATA FOR ESTIMATING REGIONAL LAND SURFACE EVAPORATION

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Within an European project on land-use and climate interactions in the Sahel, we aim at mapping regional evapotranspiration (ET) over several years at typical mesoscale resolutions (e.g. weekly, 0.5°). Recognising that ET is regulated by both the climatic environment (incoming radiation, wind speed, air temperature, saturation deficit) and the surface properties (albedo, LAI, roughness, water status), it is necessary to review the existing datasets that can potentially resolve the spatial and temporal variability of these controlling variables. We have first evaluated the available satellite observations which generally provide a good spatial and temporal sampling of the surface or atmospheric state over the past one or two decades. Despite various calibration, correction and inversion issues, it has been possible to derive such key variables as LAI, roughness (AVHRR Pathfinder) or incoming radiation (ERBE and ISCCP data). Some complementary data have then been evaluated, particularly synoptic scale ground-based datasets (air temperature, precipitation, river discharge) and AGCM reanalysis. They extend back to the pre-satellite period but suffers from sampling or modelling issues which often limit their use to coarse resolutions through e.g. climatologies. The relevance and accuracy of each source of information is discussed (intercomparison, HAPEX-Sahel data) and the promising combination of these data is illustrated through the derivation of climatological indices (potential ET) and through the guidance they provide to refine evapotranspiration algorithms (simplified relationship, Bouchet-Morton approach).

IMPLEMENTATION OF A DISTRIBUTED HYDROLOGICAL MODEL FOR THE ELBE DRAINAGE AREA USING A GEOGRAPHICAL INFORMATION SYSTEM

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A conceptual water balance and water quality model is currently being developed for the river Elbe to describe the changes in the hydrological and chemical compartments. The model is build using a Raster type GIS (PC-Raster, University Utrecht). In this paper the hydrological component is being presented. The hydrological model runs with a monthly time step and consists of two main sub-routines: soil moisture accounting and response and river routing. The model is currently being applied and tested for the Elbe river basin. The optimalization and calibration of the unknown parameters is performed automatically by using the Levenberg-Marquardt algoritm.

RESULTS OF THE GIS BASED CONCEPTUAL HYDROLOGIC MODEL ARC-EGMO IN COMPARISON WITH THE GRID BASED FULLY DISTRIBUTED DETERMINISTIC HYDROLOGIC MODEL MIKE-SHE

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There exist a lot of different complex computer models for hydrogical catchment simulation. In this study the results of simulating water balance components like infiltration, soil moisture, evapotranspiration, groundwater outflow and total run off obtained on the one hand from the GIS based, conceptual model Arc-Egmo and on the other hand from the GRID based, deterministic hydrologic catchment model MIKE-SHE are compared. The data base for the simulations consists weather data and hydrologic data for a a 3 years period as well as a GIS-data base. The recorded weather data includes daily values of precipitation, air temperature, moisture deficit of air, global radiation and wind speed. The total run off were measured on daily basis at the catchment outlet. The catchment area was about 224 km^2. The digital data base stored in the GIS includes landuse obtained from Landsat-TM satellite imagery classification, soil types, groundwater layers, groundwater levels, river network and a digital elevation model with a grid length of 50m. In the study some remarks are given about the different levels of effort to derive the necessary input data for the two different hydrologic catchment models. A further analysis is given about the different precision and the range of the various model outputs. Furtheron the limitations as well as the advantages and the disadvantages of the two different hydrologic catchment models are discussed.

HSB1 Water resources research

04 Influence of landuse and moisture feedback on continental rainfall

Convener: Savenije, H.H.
Co-Conveners: Bronstert, A.; Ulbrich, U.

IMPACT OF LAND SURFACE DEGRADATION ON CLIMATE IN TROPICAL NORTH AFRICA

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This work examines whether degradation of the land surface in tropical North Africa may be partly responsible for the persistently low rainfall in the region over the past 30 years. Comparison is made of the responses of two general circulation models (the COLA GCM and the UKMO's Unified Model) to a number of degradation scenarios in which the vegetation is made more sparse in different regions. The aim of comparing models is to identify common features of the simulations which may then be considered relatively robust features of the effect of surface degradation. Although evaporation from the surface is generally reduced by degradation the impact on precipitation depends critically on the response of the atmosphere. Differences in this response causes rainfall to be significantly reduced in some areas but not in others. In general degradation in West Africa causes local rainfall to be significantly reduced, while degradation further east does not have such a significant impact. Differences in the response of the two models are presented and comparison is also made with observed changes in the regional climate.

A CALIBRATED THRESHOLD-VALUE OF THE PRECIPITABLE WATER COMPARED TO ENERGY CONDITIONS IN THE ATMOSPHERE

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An atmospheric waterbalance is being developed to study the influence of moisture feedback in Southeastern Central Africa. This model uses a stochastic parameter of precipitable water as a threshold for rainfall to start. If the actual precipitable water is larger than the randomly drawn threshold, then the model reproduces rainfall. The amount of rainfall in the time-step (day) is proportional to the surplus between precipitable water and threshold. The proportionality coefficient can be calibrated using precipitable water and rainfall data. To assess how realistic such a stochastic model-threshold is, the threshold-value was derived for every day of upper air measurements. The 'measured' threshold is the difference between the measured amount of precipitable water and a fixed proportion of the amount of rainfall on the same day. (Multi-)regression analyses were done with energy related parameters such as Convectional Available Potential Energy (CAPE), wind speed and wind velocity at different heights. Data of Harare upper air station and surrounding rainfall gauges were used.

THE IMPACT OF SURFACE EVAPORATIVE FRACTION ON THE POTENTIAL FOR CONVECTIVE PRECIPITATION

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The impact of the land surface on the potential for precipitating convection is examined. To do so, an analytical expression that relates boundary layer equivalent potential temperature to the surface evaporative fraction is derived, by means of the slab model of the convective boundary layer. Analysis of the resulting expression shows that the equivalent potential temperature increases with the evaporative fraction under most circumstances, except for very dry atmospheres, and that this increase is enhanced in the presence of a low-level moist layer.

THE FEEDBACK BETWEEN SOIL MOISTURE CONDITIONS & RAINFALL PROCESSES

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This paper presents an hypothesis regarding the fundamental role of soil moisture conditions in land-atmosphere interactions. We propose that wet soil moisture conditions over any large region should be associated with relatively large boundary layer moist static energy which favor occurrence of more rainfall. Since soil moisture conditions themselves reflect past occurrence of rainfall, the proposed hypothesis implies a positive feedback mechanism between soil moisture and rainfall. This mechanism is based on considerations of the energy balance at the land-atmosphere boundary, in contrast to similar mechanisms that were proposed in the past based on the concepts of water balance and precipitation recycling.

CONTINENTAL PRECIPITATION RECYCLING AND VARIABILITY OF LARGE SCALE WATER BALANCE WITH LAND-ATMOSPHERE INTERACTION

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The recycling of precipitation over large land regions constitutes an effective feedback mechanism whereby anomalies in precipitation are reinforced through the soil water balance. In this paper a simple formulation of the coupled surface and atmosphere water balance is presented in order to illustrate the feedback effect. The model is characterized by independent stochastic noise forcing. It is shown that the solution to the model is a bimodal probability density function of soil moisture where each mode represents persistence (locking) in one anomaly. Mathematical stability analysis of the model equation is used to demonstrate that the bifurcation of the solution is dependent on the magnitude of precipitation recycling.

THE INFLUENCE OF VEGETATION ON MOISTURE FEEDBACK MECHANISMS AND SUMMERTIME RAINFALL IN A REGIONAL CLIMATE MODEL

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The aim of this study is to assess the role of vegetation in the soil moisture-precipitation feedback on a seasonal time scale. Four-months-long integrations are conducted with a regional climate model covering Europe. The utilized model is the "Europa-Modell" of the German Weather Service equipped with a new vegetation data set and an improved parameterization of evapotranspiration. The summertime precipitation climate depends strongly on the soil water content as has been revealed by earlier month-long July-integrations. The soil water substantially affects the partitioning of the sensible and latent heat fluxes at the earth surface and thereby modifies the soil-atmosphere feedback mechanism and the resulting distribution of precipitation. Vegetation influences this feedback mechanism, as it links the soil to the atmosphere through evapotranspiration.

The seasonal integrations start in April with saturated soil and end in July. The computed soil water distribution is realistic; this is an important precondition for further studies on the feedback processes between the soil and the atmosphere. To this end the sensitivity of the water cycle on the leaf area index is tested with special attention paid to the distribution of precipitation.

COMPARISON OF THE RAINFALL AND EVAPOTRANSPIRATION PREDICTED FOR A LANDSCAPE OF 1930, 1986 AND DIFFERENT OPEN-CAST MINING SUCCESSION LANDSCAPES

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Simulations using the landscapes of 1930, 1986, and assuming urbanization and/or different succession landscapes of open-cast mining were performed with a non-hydrostatic meteorological model. Except for the cloud and precipitating particles the diurnal domain averages of the variables of state only slightly differ under calm wind conditions. Nevertheless, the single landuse changes, which are associated with drainage, urbanization, open-cast mining or the flooding of open-cast mining, may appreciably or even significantly affect the components of the local weather over and downwind of the landuse changes. While urbanization affects the local weather the less significantly of the assumed single landuse changes, the flooding of open-cast mining causes the most significant changes over and downwind of the conversion of landuse. Generally, the most significant differences (at 90 % or better statistical significance level) occur for the liquid and solid water substances, the soil wetness and the vertical component of the wind vector. The latter differences strongly influence the paths of cloud and precipitation formation by the interaction cloud microphysics-dynamics. In contrast to all other quantities, for which a landuse change causes significant differences, the differences of the cloud and precipitating particles are not bound at the environs of the landuse changes.

THE EVAPORATION OF RAIN AND SNOWFALL IN THE SUBCLOUD LAYER

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Synoptic and aerological data from Arkhangelsk and Vienna have been used in order to derive mean vertical profiles of temperature and humidity at these two locations for days with rain and snowfall, respectively. The average height of the cloud base is obtained by combining cloud observations with the mean humidity profiles. Using climate data for the seasonal precipitation on the ground and the average seasonal number of days with precipitation, a mean precipitation rate at the ground is estimated. The mean seasonal precipitation and precipitation rate at the cloud base are obtained by calculating the evaporation in the subcloud layer. This is accomplished by solving the diffusion equation for water vapor, assuming adequate size distributions for rain and snow and employing the vertical profiles of temperature and humidity.

CONVECTIVE SCALE RAINFALL PERSISTENCE IN THE SAHEL

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This paper examines evidence of a positive feedback between the land surface and rainfall at length scales of less than 20 km. The study is based on observations from the HAPEX-Sahel field study in Niger, West Africa during 1991 and 1992. Data from a network of over 100 rain gauges in an area of 10,000 km2 operated by EPSAT-Niger are used to analyse rainfall patterns at the convective scale. The observations indicate that under certain conditions, gradients from successive storms tend to persist. The effect is sensitive to characteristics of both the surface and atmosphere. Persistence is favoured when a mature squall line passes over marked gradients in pre-storm evaporation. These surface gradients arise from soil moisture contrasts due to previous storm events. It is proposed that convection is locally enhanced when the storm passes over a previously wetted area, thus reinforcing soil moisture gradients.

Biosphere Feedback on rainfall and runoff in Tropical North Africa

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Since the late 1960s, the Sahel has experienced an extensive drought in conjunction with the desertification. The impact and mechanisms of the land surface degradation over the Sahel area on variations of rainfall and other hydrological components over tropical north Africa (TNA) are investigated using a coupled biosphere-general circulation model. This model was integrated for four years with and without vegetation change over the Sahel region. The results demonstrate that the degradation reduces the precipitation, runoff and soil moisture over the Sahel region during the summer season. The impact is also extended to the south of this area and during the autumn season. The changes in the rainfall annual cycle over the Sahel area are consistent with the observed climate anomalies of the past forty years. The runoff is reduced significantly in the desertification experiments. Using simulated and observed runoff data, the impact of degradation on river discharge variability are investigated. The observational data show the river discharge in the Sahel region is substantially reduced from the 1950s through the 1980s. To compare with the observed river discharge, a linear routing model is adopted. The lateral flow direction is taken from Total Runoff Integrating Pathway. The mean monthly discharge of the Niger river has been simulated fairly well and the simulated river discharge anomalies are in agreement with the observational data.

HSB2 Water resources engineering and management

01 Water scarcity

Convener: Savenije, H.H.
Co-Convener: Bruen, M.

Management of Water Scarcity: A Focus on Social and Economic Options

by

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Water is a scarce resource critical to social and economic development, that impacts on the behaviour of society. With close links between society and water management the importance of social and economic approaches to management of water scarcity is increasingly being recognised. The focus is here on adaptive capacity of societies, for policy making and conflict resolution, to address water scarcity and on recognising the limitations in these capabilities. Social resource scarcity could limit not only the capacity to address water scarcity but have wider social security implications for adaptive processes. There is therefore a need to develop policy options to stimulate adaptive processes and strengthen social resource capacity. Further, the paper discusses the links between water scarcity and its driving forces, such as population increase, environmental degradation and unequal access to water, and the different categories of related conflicts.
While markets could sometimes react efficiently to mitigate water scarcity, the necessary institutional conditions are seldom met. Social, environmental and equity aspects need to be considered also in a market approach and neo-classical water resources economics is loosing to economic paradigms related to political and evolutionary processes.
Also macro- and sectoral issues are on the forefront of the debate of water scarcity ranging from questions of virtual waters, high costs of O&M to privatisation of water sectors. Macro and sectoral policies often have an important impact on realisation of socio-economic and environmental benefits from present and future investments in the water sector. A country's overall development strategy and use of macroeconomic policies, including fiscal, monetary and trade policies, affect water demand and investment. As a consequence there is the need for an integrated approach encompassing social, economic and environmental policies.
Drawing from examples on water scarcity management that were presented in a recent FAO electronic conference and in regional expert consultations on water scarcity management in the Near East, the paper elaborates on these options and the practicable application for management of water scarcity at national and regional level.

Risks and hazard assessment of changing groundwater ecological state

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For estimating groundwater ecological state, aimed at proving perspectives of its use and compiling perspective plans of sustainable development for certain regions of the Volga basin, it is necessary to work out a multi - stage system for assessing its state and quality, formed under the impact of natural and human - induced factors, and perspectives for its further change under the influence of predicted climate changes. Under small - scale zoning (1 : 2 500 000), characteristic of groundwater state should base on assessing super - regional hazards and risks. Hazard from point of view of influence on groundwater state are both natural processes and some peculiarities of protective zone structure -soils and rocks in the unsaturated zone, shallow groundwater and groundwater, and mainly, human impact. Hazard is determined by HC (hazard coefficient) and HI (hazard index). For instance, to characterize the influence of the first protective zone level (soils) on the possibility of pollutants to penetrate into the groundwater, HC can be used, determined as a ratio between sand - sandy - loam sediment area of spreading and a common protective zone area) ; to describe the intensity of pollutants movement through a protective zone, HC are composed by relation between either atmospheric precipitation, or infiltration recharge, or rock saturation level and some their characteristic, or optimal values. HI is the sum of all HC, determining the hazard or the level of protective zone penetration relative. A hazard of human induced effects on the groundwater, chemical ones, in particular, can also be determined, using HC. HC values are determined by relations between pollutants concentrations and its maximum permissible concentrations. When determining HI, it is necessary to consider degree of toxicity for pollutants and to determine HI using separate categories of pollutants. Risk assessment will characterize possibility or repeatedness of pollution process by a given pollutants or group of pollutants. Total superregional risk, characterizing groundwater ecological state changes caused by natural and anthropogenic factors, will be a sum of risk, caused by the structure of protective zone and groundwater, by anthropogenic effect and actual groundwater pollution and depletion and will be material. Regional risk can be assessed during average - scale (second stage in a multi - stage system) investigations, for estimation of groundwater state changes in certain regions in a similar way (like superregional) but with a greater degree of detail and validity.. Local risks (the last stage of a multi - stage system) can be assessed under large - scale investigations, as risks, caused by local pollution sources or processes acting within local sites, these estimates must be most reliable.

SHORT DROUGHT PREDICTORS FOR AGRICULTURAL RISKS

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In this study, daily rainfall data and potential evapotranspiration estimates obtained by Penman-Monteith method are used to estimate an agricultural rainfall index as expressing the high risk of short period droughts over Greece. A water balance drought index (WBDI) defined as the percentage of days in each month with a ratio of actual to potential evapotranspiration less than 0.15 is obtained from a simple single layer water balance model and is used as a standard for predicting a short period drought. The highest probability for depleting (potentially) a 50 mm plant-available water store in inter-rain periods is investigated and 10 days are found to indicate the minimum length of the above mentioned dry period, for various areas in Greece. The estimates from the daily water balance are compared with D10 indices (calculated as the percantage of days in each month spent in inter-rain periods of 10 days or more in length) and with simpler predictors based on rainfall data as they are the mean monthly rainfall and the mean monthly raindays (RD). The D10 indices were a little better as predictors than RD and quite better than monthly rainfall. The WBDI was used as a standard in developing statistical relationships between the referred indices for 10 meteorological stations in both wet and dry areas in Greece. The predictive relationships were tested on 8 stations which were reserved as an independent validation data set.

LIBYA'S CHOICES: DESALINATION OR THE GREAT MAN-MADE RIVER PROJECT

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In the '80 s, Libya started an ambiguous project to provide water to its people: the Great Man-made River Project (GMRP). It is one of the largest civil works projects in the world, involving the pumping of ancient groundwater from the Sahara desert and transporting it hundreds of kilometers to the coast of Libya where demands for water exist. The Great Man-made River Authority (GMRA) wondered whether and how the GMRP infrastructure should be expanded. GMRA, responsible for water supply development and operation in Libya, asked UNESCO to perform an economic analysis on this issue. The study identified least cost combinations of investments in desalination plants and the Great Man-made River Project, that would meet specified water demands at various locations throughout the country. The author, contributor to this study, discusses the LP-models used and presents some interesting results. It is concluded that desalination appears to be an economically efficient expansion alternative only for a very limited range of water demands scenarios, given the investments already made in the GMRP.

ON-FARM GREEN WATER ESTIMATES AS A TOOL FOR INCREASED FOOD PRODUCTION IN WATER SCARCE REGIONS

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Rainfed agriculture covers > 95 % of the crop lands in water scarce tropical regions, and will in a forseeable future be the dominating source of food for growing populations in the tropics. Despite this fact, focus has until recently been on the potential conflicts and resource scarcity related to the water used for irrigated agriculture, industry and households - the so called "blue" water recharging rivers, lakes and aquifers. Yield levels have to increase substantially in order to guarantee a minimum of livelihood security in dry tropical regions. This paper focuses on the potential of improving the efficient use of rainfall through integrated soil nutrient and water management. Results are presented from an on-farm water balance research project on pearl millet in the Sahel (Niger). The findings indicate that only a very small fraction of the rainfall, 4 - 9 %, takes the productive water flow path as "green" transpiration water. Surface runoff was substantial, amounting to 25 - 50 % of rainfall for intensive events, despite sandy soils. Extremely low canopy cover explains why the losses of improductive soil evaporation amounted to around 50 % of annual rainfall. Drainage was significant in this dryland farming system, despite the presence of periods of severe water scarcity during critical growth phases. Very low water use efficiencies were observed indicating a large potential for increased yield and "green" water flow. An option discussed is water harvesting techniques for supplementary irrigation.

WATER SCARCITY MANAGEMENT IN UZBEKISTAN

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Water scarcity management in arid zones in developing countries connected with institutional development of water sector. Actually in this case the scarcity is a consequence of uneffective water use. Rules and mechanizmes offered for water conservation and water market promotion. Developed water allocation model (on GIS base) showed that market of saved water can be effective for agricultural water users. Efficiency of reallocation of water scarcity and water conservation measures presented with GIS implementation for some irrigation zone of Uzbekistan.

METHODS OF OPTIMAL IRRIGATION MANAGEMENT UNDER THE CONDITIONS OF DEFICIENCY OF WATER AND POWER RESOURCES IN THE UKRAINE

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The deficiency of sweet surface waters and power resources stipulates the necessity to use resource-saving technologies in waterings' planning and water-distribution on the irrigative systems of Ukraine.
Toward this end the complex of information-computative system of long-term and operative planning in irrigation was worked out.
The models for planning of water-saving and ecologically safe regimens of irrgation as well the algorythms of optimization of water-distribution under the resource deficiency were realized in the composition of the system. The application of ICS for irrigation planning in the Ukraine makes possible to economize up to 20-30% of water-power resources, to reduce the losses of yield under the resource deficiency.

DETERMINATION OF THE MAXIMUM IRRIGATION EFFICIENCY OF GOLF COURSES IN SEMI-ARID MEDITERRANEAN CLIMATE

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Many golf courses have been constructed along the Mediterranean coast where water supply for other more important uses is not sufficiently satisfied. In this context is important the development of water saving strategies.

The determination of a maximum irrigation efficiency depends of the water budget concept where inputs to the system include precipitation, capillary rise and irrigation and by other hand, outputs include turfgrass water use, evaporation from the soil surface, runoff and infiltration beyond the root zone. The amount of reserve moisture available to the turf, that depends primarily on the soil texture, plant root depth, can be now easily measured by means of TDR probes.

This paper shows how the development of more saving watering methodologies together with a natural course design using mainly actoctonous less consuming turf specimens could help to reduce this problem.

HSB2 Water resources engineering and management

02 Sustainable development of watersheds and river processes

Convener: Habersack, H.M.
Co-Convener: de Groen, M.

River Flow Objectives: why and how

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This paper reviews the concepts behind management of river flows for environmental purposes, and the methods that may be used to determine such flows. Ecological management of river flows is receiving increasing attention world-wide. Although international co-operation has led to important developments, assessment methods must be tailored for specific river types, administrative arrangements and level of contention. We have reviewed a range of specific methods: static and dynamic hydrological indices, baseline data collection, discussion-based approaches and bottom-up simulation modelling techniques. We have also considered the characteristics that appear to relate to the success of such determinations, along with the potential advantages and disadvantages of having such objectives. Of key importance is an overall national framework for environmental flow determinations, incorporating guidelines for a cross-functional approach.

SUSTAINABLE MANAGEMENT OF A RIVER WITH A CASCADE SYSTEM OF HYDRO-POWER PLANTS

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The complex of various industries (energy-production; agriculture; municipal and industrial water supplies etc.) functions in river basins. Each of them has its interests which are often contradictory. It is important to govern the water-management complex with regard to the environmental protection (sustainable management). Therefore, it is necessary to create the co-ordination centre for the effective co-operative work of the water-management complex.

The prepared method of the management of a cascade system of hydro-power plants, developed using the automatic control system, takes into account the requirements of all branches of the water-management complex from the point of view of ecological safety. The choice of the rational cascade regime is directed by many parameters due to the necessity of consideration of all participants of the complex in the water-basin. Actions during the management of the cascades regimes during the exploitation period are based on the automatic process control system and the results obtained using the local terrain-basin monitoring system. The latter provides the total account of the ecological requirements.

This method has been proven to be very efficient during the simulation design of the Kem (Karelia) and Tuja-Mujun (Uzbekistan) water-basins.

THE MORPHOLOGICAL AND HYDROLOGICAL IMPACTS OF GRAVEL-MINING IN THE BØVRI, NORWAY

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Gravel has been mined in the Bøvri, part of the Glomma river system in south-east Norway, for the last 20 years. The morphological and hydrological impacts of this mining activity has been investigated using river channel profiles to quantify channel change in the period. 66 cross profiles taken over 6 km of the river were measured in 1976 and remeasured in the spring of 1997 and again in the autumn of 1997 after a large spring flood. The two sets of profiles measured this year enable, in addition to monitoring the long-term effects in the river, the effect of a large flood on the rivers morphology to be measured. Gravel-mining in this river is controversial. The river is a protected watercourse and environmentalists protest that gravel-mining disturbs the natural morphological processes, is a visual eyesore and leads to erosion. Local farmers on the other hand argue that the gravel-mining helps keep the river at an acceptable level and that the mining is kept at a sustainable level. This proglacial river is naturally heavily loaded with sediment and this may be a viable argument. The profile data, together with discharge and water level data, has enabled the water level at different discharges in both 1976 and 1997 to be modelled and will help resolve part of the conflict between local interests and environmental concerns. The results of this investigation are presented in this paper.

SUSTAINABLE AND ECOLOGICALLY SOUND DEVELOPMENT OF WATERSHEDS AND RIVER PROCESSES

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Concerning river engineering and management a holistic vision based on the whole catchment ecosystem is required. In order to get a holistic answer for defined problems analysis at different scales have to be performed. In the paper it is suggested that a procedure consisting of two major steps should be applied. First a downscaling process leads to the problem definition, various aspects of sectional and local investigations and finally to the point scale, where basic data are measured and parameters for the larger scale models are calculated. There process oriented, deterministic models and direct measurements dominate. The upscaling process is necessary to get at least to the sectional scale, where engineering measures are planned. For some aspects like the increase of the input of sediments into rivers with bed degradation problems the management of sediment regime in the whole catchment is essentiell. There mainly stochastic models and indirect monitoring methods are used. Although many different models and monitoring methods exist in the various scales no sufficient methodical means for the down- and upscaling process have been developed up to now and should be a cause for further research in the future.

MATHEMATICAL MODELLING OF SUSPENDED LOAD IN PTUJ LAKE

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Abstract. A two-dimensional depth averaged mathematical model for the calculation of transport and sedimentation of suspended load in a river reservoir is presented. It is composed of hydrodynamic and sediment transport modules. The model was applied to the Ptuj lake on Drava river where some necessary measurements of flow and sediment characteristics were performed in 1993. On the basis of the measured data the model was satisfactorily calibrated. At the end some results of the computed flow pattern and settled material in the lake are shown.

TIME SERIES ANALYSIS OF DISCHARGES OF THE SAONE RIVER

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Considering the flat topography of the Saône river area and the economic importance of the Saône-Doubs-axis, it has to be stated that changes of runoff processes in the Saône catchment have significant effects. Such changes can be assumed for the 20th century since an investigation of climatological data and a literature research concerning anthropogenic activities in the catchment reveal a considerable variability of important regime factors. Thus reasons are given for a corresponding analysis. Thereby conclusions are drawn from a series of mean diurnal discharges from 1920 until 1995, observed in COUZON (about 17 km away from the confluence with the Rhône). Different annual series (means, maxima and low-flow parameters NM7Q) and monthly series (means) are generated and divided in three sub-series. On these sub-series different methods of time series analysis are applied: trend analyses and moving averages for the detection of central tendencies and methods for the investigation of discharge variability including flow duration curves, FOURIER and autocorrelation analyses of mean monthly discharges and frequency analyses of extreme events. The comparison of results of different subseries reveal that the runoff situation in the Saône catchment has significantly changed during the 20th century. Problems due to these changes may occur, e.g. regarding the flood situation. Possible causes of the changes are dicussed including the results of the literature research.

PESTICIDES TRANSFER BY RUNOFF AND EROSION FROM FIELD TO AGRICULTURAL CATCHMENT

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Water erosion of cultivated soils promotes water pollution by pesticides in solution or adsorbed on suspended particles. The aim of this work is a multi-scale study of transfer processes of two pesticides used in cereal cultivation : diflufenican (DFF) and isoproturon (IPU), the latest being more soluble in water and less easily adsorbed on soil particles. Experimentations are made on plots from 10 m² (simulated rainfall) up to 500 m² (natural rainfall) with grassed buffer strips and on various types of cultivated catchments. The processes of products mobilisation by runoff, trapping effect and catchments field pattern influence on pesticides transfer are analysed. Particularly, the influence of soil surface degradation on herbicides transfer were studied on 10 m² plots under simulated rainfall. The extent of pollutants transfer from the field to the catchment was investigated by : (1) Study of grassed buffer strips of different width located downstream to winter wheat plots with runoff measurement and water sampling ; (2) Study of catchments with on-farm studies (to determine inputs and treatment dates), direct observations (to characterise soil surface degradation on all agricultural plots), flow measurement and water sampling at the catchment outlet. The use of a GIS in combination with these results will allow an impact assessment of different soil conservation schemes and the extrapolation of the results to other catchments.

SIMULATION OF NITRATE POLLUTION FROM AGRICULTURAL USED LAND IN A SMALL RIVER CATCHMENT OF NORTH-EAST GERMANY.

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Nitrogen leaching is one the severe problems for water resources in areas of intensive agricultural land use. With the help of simulation models the effects of land use and agricultural management practices on the quality of the seepage water can be analysed and strategies to improve water quality can be tested within scenario studies. We investigated land use and agricultural management practices in a small water catchment (224 km²) of north-east Germany for a period of 3 years. Based on these geographically referenced data and digitized soil maps we used a relative simple regionalized simulation model which describe the main processes of the nitrogen dynamics (water balance, nitrogen mineralization, denitrification, nitrate transport, N-uptake by plants) of the soil-plant system. Results were compared with measured deep profiles of nitrogen upto 4.2 m. The model was able to reflect well the effects of different farm management systems. Based on the results for the present situation scenarios were calculated to evaluate sustainable land use strategies within the catchment.

CRITERIA OF TECHNOGEN TRANSFORMING OF RIVER FLOW

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A technogen transforming of river flow is connected with many factors. Therefore, it forms differential measures systems of evaluation(criteries) of each factor. This reguires enguring of detail hydromelerological and hydrochemical information. In conditions of unsufficient observation data especially about flow diversion, it can be used common criteries of flow transformation, flow and salt mass. The processes can be analysed through hydrodynamic model of flow with differential mass. The model was applied for criteries development. Flow transformationin irrigation zone, this is a common for the system criteria, partical criteries are flow changes and volume of water diversion for different technological processes. On the same base elaborated criteria systems for salt flow. These criteries system applied for predicting of flow for Syrdarya river and other rivers of Aral sea basin.

THE EFFECTS OF INACCURaTE INPUT PARAMETeRS ON SEDIMENT TRANSPORT CALCULATIONS

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Calculation of sediment transport processes is a very difficult task. Due to the many influencing factors of sediment tranport and the impossibibity to develop a fully valid physically model, there exist many approximate models to simulate the process of sediment transport. For engineering predictions in unsteady flow, there exist numerical schemes to solve the St. Venant equations in one or two dimensions, coupled with an equation for the sediment tranport. The problem is not only the accurate calibration of the model but also the acquisition of realistic values for the various input parameters. For most of the parameters we have to consider their spatial and/or temporal stochastic nature, and therefore we must describe them as random variables or spatiotemporal random fields. Sediment tranport models are therefore random processes. The results obtained depend on the stochastic nature of the input variables. It is important to know how the simultaneous inaccuracy of the various input parameters influence the result gained and to identify those parameters which determine the process most. The well known first order reliability method is a useful tool to assess the influence of stochastic input variables to the calculated result. In this paper we will show how this method can be applied to judge quantitatively the influence of the inaccuracy of the different input parameters of transport formulas. We will also give results of inaccuracies of calculated suspended load concentration and deposition rates in one dimensional unsteady flow.

IMPACT OF RESERVOIRS IN RIVER SEDIMENT TRANSPORT REGIME A CASE STUDY IN TAGUS RIVER BASIN

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The construction of dams leads to sedimentation in reservoirs and to degradation in the lower parts of rivers, caused by the decreased volumes of sediments transported maintaining however a similar transport capacity. Experimental finding of these phenomena was obtained from surveying campaigns carried in the 70┤s, 80┤s and 90┤s decades where data derived was used to characterise the impact of reservoirs in sediment transport regime, in terms of suspended sediment transport and granulometric distribution of bed material.

ASSESSMENT OF EMBANKMENT REMOVAL EFFECTS ON GROUNDWATER DYNAMICS IN AN ELBE RIVER FLOODPLAIN

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At the Elbe River, which has been modified by regulation and embankment construction for centuries, multidisciplinary research efforts are currently conducted to increase the understanding of regulated river ecology (Projekt Elbeökologie). At the study site in Lenzen, in the Elbe National Park, embankment removal is being considered to increase the hydrological connectivity of the river-floodplain system. In order to develop restoration strategies for floodplains a total of 9 related projects examine the interplay of ecosystem processes. The integration of hydraulic, ecological, and economic aspects of the research will proceed through: (1) identifying present and predicting patterns of groundwater dynamics, (2) developing techniques of assessing the estate of the floodplain ecosystem and (3) developing models to explore the effects of the reinstatement of flooding after the removal of the embankment. The presentation will focus on the river-aquifer interactions. In order to inspect the exchange conditions, several groundwater observation wells were installed, the hydrogeological situation characterized and a finite element groundwater model of the floodplain was set up.

THE PASSAGE OF RIVER- AND GROUNDWATER THROUGH A RIFFLE

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The hyporheic zone, with its spatial and temporal dynamics, is highly relevant to the ecosystem river. It is defined as the part of the river bed that is dominated by the exchange of channel flow and groundwater and has a specific biological settlement The zone covers aproximately the first 50 cm of the river sediment and is therefore very important for the rivers solute transport and storage.
The exchange through the hyporheic zone of two pool-riffle-sequences in the medium scaled River Lahn (Gernnay) is analysed and described numerically within an interdisciplinary projekt. The aim is to gain insight into the spatial and temporal dynamics of abiotic parameters and biological processes in the hyporheic zone.
First results show that the riffle can be devided into two zones where either inflow or outflow is dominant. One of the most interesting questions that has arisen involves the way in which channel flow and groundwater initiate the in/outflow in the riffle sediment and the relevance of morphology and sediment characteristics. The current flow through the riffle can also be observed when analysing the chemical compound of the pore water. The results show conclusively the coherence of abiotic parameters and biological settlement.

DISTRIBUTION OF LARGE WOODY DEBRIS ALONG A MOUNTAIN RIVER CONTINUUM, THE DROME RIVER, FRANCE

(Guidelines to manage fish at a watershed scale)

H. Piégay, A. Thévenet & A. Citterio1

Large woody debris (LWD) are considered as an important fish habitat. Characteristics, mass and distribution of LWD were also studied along a 100-km long reach of the Drôme river, France. The goals are to propose few guidelines to manage fish habitat at a watershed scale. Numerous LWD accumulations were observed within the active channel (low-flow channels and gravel bars) located in a limited number of preferential sites. In contrast, LWD in the low-flow channel were unfrequent and randomly distributed all along the river course. Bank erosion is one of the main sources of LWD input. The active channel also stocked 2.5 to 3.7 times the annual floodplain LWD inputs estimated for the period 1971-1991. LWD accumulations are very unstable and are generally located on bars, demonstrating that their location is linked with the decrease of flow level in shallow sectors and not because of a stop-en-route caused by in-channel structures such as boulders or vegetated islets. Consequently, LWD accumulations on the Drôme river have a negligible morphogenic role. These results allow to conclude that to improve fish habitat in the Drome River, a temporal and holistic perspective larger than the local site is recommended. Because structures placed in this unstable channel are likely to be washed downstream, we propose to emulate natural river dynamics and to permit large woody debris to enter the channel in unstable reaches via bank erosion, and that this debris not be removed (as is routinely done now) but permitted to migrate downstream through the system, creating fish habitat enroute.

A REGIME APPROACH TO THE PREDICTION OF DREDGING ACTIVITIES IN TIDAL RIVERS

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The continuing and increasing commercial, social and industrial demands for developments on and in rivers and estuaries, has been accompanied by a greater need for improved and more accurate techniques for the prediction of the longer term effects of these developments. For rivers and their estuaries, which have been or will be subjected to engineering works, it has become increasingly important to evaluate and predict the environmental impact of the works within the context of sustainable development. The application of a numerical hybrid model, based on the regime approach, to the prediction and evaluation of the long-term effects of dredging in a tidal river is described.Dredging has the potential to cause extreme changes to the behaviour of tidal environments, in particular to the patterns of sediment erosion and deposition.These changes are not localised or short-term, and can have an impact on the whole of a river/estuary system.
It is shown that the approach could provide a useful modelling tool in the assessment and evaluation of the sustainable development of a tidal watercourse.

03 Remote sensing and GIS in hydrology

Convener: Baret, F.
Co-Conveners: Estrela, T.; Stips, A.

GROUNDWATER SYSTEMS MANAGEMENT FOR DRINKING WATER SUPPLY OF BUCHAREST CITY, ROMANIA

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The paper presents the hydraulic and geologic characteristics of the aquifer systems that provide more than 20% of the needed water for drinking water supply of Bucharest city, the Capital of Romania, that has more than 2,300, 000 inhabitants. The specific consumption is very big, around 820 litters per inhabitant and day, and with all this is considered now to be insufficiently, taking into account the frequently protest of the people. There are registered, often, many switches off of the water supply system and many diminution of pressure along the distribution network, spread unequal over the area of the city. These are caused, on the one hand, due to the insufficient yield capacity of the aquifer and extraction system, and on the other hand due to the large losses from the distribution system (that can be around 40% from the total water flow). The solutions that are proposed act in two directions: the improvement of the extraction system and the rehabilitation of the distribution system.

IMPROVEMENT OF PERFORMANCE INDICATORS DUE TO CONJUNCTIVE USE OF SURFACE AND GROUNDWATER IN COMPLEX WATER RESOURCES SYSTEMS

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The great complexity of many water resources systems makes it very difficult to properly quantify the limits to increase the use of water and to evaluate the possibilities that could be obtained from the conjunctive use of surface and groundwater. The answers to these key questions should be obtained in a way that several infrastructure configuration scenarios could be accounted for and that different water supply performance constraints could be assumed. A methodology to reach the above goals is presented. It is based on the use of a water resources simulation model that integrates the simulation of the groundwater system fully incorporating aquifer models of distributed parameters. With this model the simulation allows to study the maximum demands that can be served for given performance constraints, considering different hypotheses for infrastructure configuration, aquifer exploitation and seasonal distributions of demands. First the simulations are carried out for a set of fictitious water demand units distributed in the system and then the actual demands are considered. This approach is currently being applied in several spanish river basins where groundwater exploitation is an important issue. Thus the increment of resources due to the conjunctive use and the limits imposed by the hydrological inputs in the basin are estimated. Additionally, a better global understanding of how the system works is obtained.

APPLICATION OF NON-CONVENTIONAL HYDROCHEMICAL PARAMETERS DETERMINED BY ICP-MS TO GROUNDWATER MANAGEMENT OF THE AQUIFERS OF THE LLOBREGAT RIVER

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The high concentration of inhabitants (over one million) and industrial density of the lower valley and delta of the Llobregat River, near Barcelona (Spain), make the groundwater management of the alluvial aquifer system particularly difficult. Major elements and physico-chemical parameters have been traditionally used to characterise groundwaters. In many cases this information has not capability to differentiate between waterbodies. Inductively coupled plasma-mass spectrometry (ICP-MS) provides concentrations of the trace elements implied in natural and anthropogenic processes, being decisive for groundwater management. A sampling net of ninety-six points has been defined. Conventional and non-conventional hydrochemical parameters (twelve major elements and fifty-eight trace elements) have been determined by means of ICP-MS, using their multielemental capability to carry out a complete scanning of the groundwater system. After a complete study twenty-three of the above-mentioned parameters have been retained in order to fingerprint the waterbodies. This hydrochemical information allows us to discriminate samples of different waterbodies with similar chemical signatures on conventional parameters and plot more easily the trends of the system, essential for its management. This work is supported by a CICYT project (HID96-1290).

DEVELOPEMENT OF CONTROL AND DECISION SYSTEMS APPLIED TO THE MANAGEMENT OF COMPLEX HYDROLOGICAL RESOURCES

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The Salado River lower basin in the eastern Argentinean Pampa has experimented a notable change in the last ten years as result of agriculture and cattle-rising increased development, assisted by intensive technological equipment, as well as industry, affecting surface and groundwater quality.
The study of surface waters and groundwaters of the Salado lower basin, using over forty hydrochemical parameters, allows us to establish three primordial hydrological systems (the groundwater system, the lacustrine system and the fluvial system) and the reference levels of the hydrochemical parameters. Even though the three systems are interconnected, the hydrological fingerprint of each system allows its clear identification. Furthermore, the main processes affecting the area have been determined: groundwater nitrate pollution, lacustrine systems eutrophization and local high levels of potentially toxic trace elements.
A bilateral co-operation project involving the University of Buenos Aires (Buenos Aires, Argentina) and the Generalitat de Catalunya (Catalunya, Spain) supported this work.

OCCURRENCE OF HEAVY METALS IN GROUNDWATER AND SURFACE WATER RELATED TO MINING ABANDON (LINARES, SOUTH SPAIN)

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An important mining activity on metallic sulfides ores (dykes in a granitic batholith), now abandoned, was historically developed in the Linares area (Jaén, Spain) till the 1980s. The old mining works (pits, galleries) are currently flooded, after the finishing of dewatering operations. These mining holes are now responsible of the storage and transmission of groundwater within an igneous complex of basically impervious behaviour. An increasing exploitation is taking place in recent years for agricultural purposes, pumping directly from the mining holes and, consequently, modifying batholith hydrodinamics. Important modifications on groundwater hydrochemistry could be induce due to: 1) piezometric drawdowns, which are controlled by the exploitation regime and 2) changes from phreatic to vadose conditions in the groundwater-mineral system, resulting in a significative change in redox environment. Chemical analysis of groundwater from ancient galleries show high values for Al, Cr, Cu, Fe, Mn and Pb. In addition, highly pollutant leachates from old mining tailings have been detected (surface water in ponds with several mg/l contents in Cu, Fe and Mn). At present, mobilisation of these heavy metals towards the streams and its sorption in agricultural soils and fluvial sediments is being analyzed.

KARST GROUNDWATER MANAGEMENT AND PROTECTION

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In recent decades, two opposite processes were developed simultaneously - water consumption increase, in one hand, and water resources pollution and overproduction, on the other. That is the reason why water global problem, that is - drinking water problem, as one of the most important in complex of environmental protection measures, has originated.

In the paper, ways of better groundwater resources management in karst water-bearing terrains are analyzed. Among the others, great abilities of karst aquifers for various artificial interventions (regulations) taking, in order to increase groundwater resources exploitation, are discussed.

THE DYNAMICS OF MAIN FACTORS OF GENESIS IN RIVER MOUTH REGIONS UNDER DIFFERENT ANTHROPOGENIC LOAD

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The objective of the investigation is the establishment of main factors of genesis of river mouth's bottom natural complexes (BNC) at different levels of anthropogenic load. The data of large-scale landscape observations in the mouths of small rivers falling into the Sea of Japan (at the Russian Far East coast) have been used. The data have been treated with the aid on the basis of factor analysis. Most river basins are areas with small population and without industry. At several river basins, mines and plants are situated and pollute the river mouths and neighbouring shallow sea zones. The comparison of main factors for river basins without man's activity and with anthropogenic load give opportunities to estimate consequences of river basin pollution in genesis of river mouth BNC and to predict possible change of these complexes at different human impact.

OPTIMIZATION AND DECISION ANALYSIS OF REMEDIATION DESIGN

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The choice of a ground water pollution remediation strategy is a difficult decision in a realm of uncertainty. The work here is a preliminary investigation into optimization between remediation strategies, under parameter uncertainty and considering strategy reliability for ground water pollution. Reliability and cost are the factors in the objective function used in a genetic algorithm optimization. Artificial neural networks are used to reduce computational burdens, they are used in sensitivity analysis and within the evaluation of the objective function. Numerical models are used to develop the training sets for the artificial neural network. The results of the optimization are placed into a decision analysis framework to improve the transparency of the results of the optimization and the implications of low reliability. In at trade-off curve presentation of the optimization results one sees a more complicated relation between reliability versus cost than previously presented in the groundwater literature. This is attributed to the inclusion of secondary remediation costs within the objective function, and those costs are discounted by the failure rate of the primary remediation technology.

MAGNETIC TREATMENT OF SALT AND GROUND WATER

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Agricultural practice in arid areas is closely connected with possibility of application of salt and ground water for irrigation. The high mineralization and alkalinity of marine and ground water requires making some additional engineering decision to change their physico-chemical properties and decrease of their alkalinity. As a method for alkalinity decrease of natural water the method of water magnetohydrodynamic activation maybe proposed. As a rule ground water is of hydrocarbonic type. It has high carbonic hardness and alkalinity, oversaturation in $CaCO_3$ and $CaSO_4$. Its spontaneous use for irrigation is not admissible. Water magnetohydrodynamic treatment shifts the carbonic acid balance in water, reduces alkalinity, changes gas content and salt crystallization rate. The method is free of chemical reagents and it is ecologically pure. The field trials of the magnetic apparatus for salt and ground water in Turkmenia shows positive results.

GROUNDWATER MIXTURES DUE TO PUMPING IN THE DETRITAL TERTIARY AQUIFER OF MADRID

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The aquifer of the detrital Tertiary of Madrid is geochemically stratified. This aquifer provides the city of Madrid with groundwater through deep wells, (some exploration wells are over seven hundred meters deep), and is observed that productive levels change in composition in-depth. Drilling operations produce changes in that stratification, due to the mixing processes, and makes difficult the identification of the original chemical facies. Sampling of two deep wells, over the step-by-step pumping tests, partially allows the identification and discrimination of those original hydrochemical facies. In addition, further hydrogeological features can be deduced.
Water pumped out from wells comes from different levels and displays different proportions of mixture. The chemical characteristics of the mixture are well defined and are a function of the level transmisivity. In the study wells, the amount of mixture of the lowest levels increases in accordance with the depression of the dynamic level of pumping. Na+ is the most important ion followed by SO42- and Cl-.
The occurrence of HCO3- is associated with water from shallow levels. The clear predominance of Na+ is conditioned by the significant alkaline exchange in the aquifer. This work is supported by a CICYT project (HID96-1221-E).

GIS BASED HYDROGEOLOGICAL DATA MODELS FOR GROUNDWATER MODELING IN MESOSCALE PLEISTOCENE WATER CATCHMENTS

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Existing groundwater modeling systems (FEFLOW, MODFLOW, ASM) are suited for detailed hydraulic groundwater modeling in areas up to 50 km². To apply those models into mesoscales consider detailed information about the extremely heterogeneity of hydrological and geological boundary conditions, especially in the pleistocene landscape of NE-Germany. In this area a high density of data will be necessary to describe the hydrogeological situation accurately. Data collection using boreholes and mapping results requires expansive financial and personal efforts, therefore such methods are not practical in mesoscale groundwater modeling.
Based on GIS technologies a method was developed to describe the hydrogeological conditions of aquifer systems in pleistocene regions larger than 200 km² using available hydrogeological data and digital elevation models. The resulting data models describe the real heterogeneity of the hydrogeological situation by exercising systematically simplifications using transmission and weighting of scale depended parameters. The level of simplification is adaptable to the requirements of modeling. The application of this method will be shown by modeling results of ground water movement and matter transport in a mesoscale pleistocene aquifer system.

HSC1 Special hydrological symposia

01 The French National Programme in Hydrology

Convener: Vauclin, M.

DYNAMIC HYDROLOGY OF THE SOIL SURFACE.

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Better understanding of the mechanisms controlling the partition of precipitation between runoff and infiltration in real soils is one of the crucial barriers to effective modelling of soil erosion by water, particularly at hillslope and catchment scales. Many studies demonstrate the importance of soil surface characteristics on infiltration rates. Microtopography and soil crusting in particular influence the pattern of ponded infiltration, overlandflow velocity and rill initiation and are themselves modified dynamically by rainfall and cultivation. The RIDES project will focused on the runoff/infiltration partition, with particular reference to the influence of local heterogeneities and their impact on the areal distribution of sediment transport. The research will associate descriptive measures of the soil surface features with detailed measurements to build a typology which can be rapidly applied at field and catchment scales. Methods proposed include in situ measurements of hydrodynamic characteristics through rainfall simulation and tension disk infiltrometry; and the use of isotopic and chemical tracers to observe the dynamics of surface and subsurface moisture reservoirs during and after natural and simulated rainfall events.

UPSCALING DISPERSION IN HETEROGENEOUS MEDIA : NON-EQUILIBRIUM MODELS

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The transport of solutes in geological formations is currently receiving a great deal of attention for issues such as remediation of contaminated groundwater. The presence of heterogeneities at different scales leads to anomalous dispersion at the field-scale, which cannot be described using the advective-dispersive transport equation. The transport of solutes is considered when the condition of local equilibrium between the different regions is not valid. An up-scaling method such as *the method of large-scale averaging* is used in order to take into account heterogeneities, and give a macroscopic representation of solute transport. This method calculates the transport equations and the effectives properties at a given scale by an averaging process over the equations corresponding to the lower scale. Under some length scales constraints, a first order development leads to a set of two large-scale equations for a two-region medium. The resulting local non-equilibrium model can be seen as an extension of dual-porosity models. A numerical procedure is proposed to calculate the macroscopic transport coefficients for any geometry. In order to test the two-equation model, theoretical results are compared to numerical experiments. With stratified and nodular systems, the results show a reasonable agreement between theory and experiment. Finally, a numerical algorithm for solving the inverse problem is implemented to evaluate the large-scale effective properties in order to characterize natural porous media with laboratory experiments.

Rainfall statistics at small time steps in the Sahel : a preliminary investigation into the validation of a desaggregation model

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The French "Programme National de Recherche en Hydrologie" (PNRH) is supporting a research aimed at developing a model adapted to the disaggregation of the rainfields associated to the Sahelian Mesoscale Convective Complexes (SMCC's). The space component of the model is based on a turning band algorithm. The time disaggregation is obtained by moving a standard hyetogram across the simulation domain. The parameters of the hyetogram are varied at each point so as to condition the peak intensity on the point cumulative storm raindepth resulting from the space disaggregation. Since in the Sahel hydrologic processes are especially sensitive to small time step fluctuations of the rainfall input, it is important for the disaggregation model to be able to reproduce correctly some basic rainfall statistics at typical time steps of 5 to 15 minutes. As a preliminary insight into this question a few results are shown here regarding : i) 5 minute statistics retrieved from the EPSAT-Niger data set ; ii) comparison between these observed statistics and those produced by the model. These results have important implications for our understanding of the rainfall variability at various time scales and for the validation of the disaggregation model. Space variability at the storm scale is primarily linked to the distribution and dynamics of convective sells in space. This translate into a cumulative frequency distribution of 5 minute rainfall that can vary significantly form one station to another at the seasonal scale. On the other hand, when considering the 5 minute rainfall distribution averaged over all the stations for a given season, it is shown that it varies little from year to year. The model appears to reproduce correctly these features, with some significant discrepancies however that could lead to a modification of the disaggregation algorithm.

ISOTOPIC COMPOSITION OF WATER FROM TERRESTRIAL PLANTS: IMPLICATIONS FOR WATER SOURCES AND WATER VAPOR

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The exchanges of moisture between leaves water and atmosphere have been investigated under controlled, simulated environmental conditions. Daily variation of the isotopic composition of water in leaves was performed to study the relations between the transpiration process and the increased isotopic enrichment observed in the remaining water in the leaves and in the water vapor provided by transpiration. The daily enrichment cycle of ^{18}O and ^{2}H observed in the leaves water fitted a classical model of water fractionation based upon the theory developed by Craig and Gordon (1965). The discrepancies between the measured and the calculated values seem to be closely related to the differences between the isotopic composition of the water pools in the leaf. Results show that the transpiration flux produces an isotopic enrichment in the surrounding environment of the leaf by returning to the atmosphere the isotopic composition of the source water when the leaf water reached an isotopic steady-state. Then stable isotope composition of water vapor may be used to study the interaction between regional air masses and local evapotranspiration. To confirm such a conclusion, additional observations of the evolution of the isotopic composition of water vapor during the growing season are required to estimate the influence of the canopies on the atmosphere.

EXPERIMENTAL AND NUMERICAL STUDY OF MISCIBLE FLUID DISPLACEMENTS IN POROUS MEDIA WITH LARGE HETEROGENEITIES

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An experimental and numerical study of the displacement of a fluid by another in porous media with large scale heterogeneities is reported. The objective is to relate the displacement front geometry to heterogeneities of the medium. Experiments are performed both in 2D Hele-Shaw cell models using optical observations and image analysis and in 3D packings of glass beads with an acoustical technique provided an image of fluid displacements. Permeability heterogeneities are modeled in the first case by thickness variations and in the second by varying the diameter of the beads. Front displacement tracking and flow line visualizations on the Hele-Shaw cell allow to determine the velocity field. Acoustic images in the 3D model confirm the analogy between the two systems. Experiments with fluids of same viscosity with a stabilizing density contrast confirm that the front extent is reduced by gravity at low velocities. Experiments on matched density fluids with a stabilizing viscosity contrast display at high velocities a narrower front width than for matched viscosities. Numerical simulations are performed in the same geometry using a Boltzmann lattice gas technique : a Stokes-like diffusive term is introduced to smooth out the effect of permeability discontinuities. Numerical simulations reproduce experimental results and can be extended to fluids with other physical properties.

MUREX: A LONG TERM FIELD PROGRAM DEDICATED TO THE MEASUREMENT AND MODELLING OF THE HYDROLOGICAL BALANCE AT A FALLOW SITE IN SOUTH WESTERN FRANCE.

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In the past, several field programs have been conducted for validation of Soil-Vegetation-Atmosphere (SVAT) Models, e.g. HAPEX-Mobilhy, FIFE, EFEDA, HAPEX-Sahel... However, the limited duration of such campaigns (no more than two months) did not allow to test model ability to reproduce the annual or inter-annual water cycle. Longer validation datasets are required. The motivation for a long term field documentation of relevant processes came from the PILPS intercomparison exercise. This intercomparison of surface schemes used in Global Climate Models showed that the accuracy of climate predictions are very sensitive to the description of the water cycle.
MUREX started in june 1994, and should be completed in spring 1998 after the recharge of the soil. The talk will include both a description of the complete set of measurements, and model results using two kinds of SVAT models: a rather simple one (ISBA), suited for coupling with meteorological or climate models, and a more detailed one, i.e. SISPAT.

ON UNIQUENESS OF PLACE IN HYDROLOGICAL MODELLING

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Recent discussions of hydrological modelling in the *Tribunes Libres* of de Marsily (1994) and Ganoulis (1996) have been concerned with the problem of scale as a limitation on hydrological modelling. Both suggest, from different viewpoints, that it is necessary to develop and apply hydrological theory at appropriate scales in order that any parameters should be physically meaningful. Even then, they argue, imposing constraints on model predictions for a particular application will be uncertain, a process of conditioning rather than specification of parameter values. Such conditioning is the saving of hydrological modelling in the face of uniqueness.

It is this conditioning that will be discussed in this presentation. This conditioning takes place in the context of the uniqueness of place of any application of a model. Knowledge of that uniqueness (in space, time and action) is inevitably limited by measurement techniques and resources. The nature of the uniqueness is not normally reflected in model structures, which seek unity in the sense of de Marsily, but in the possible parameter sets that will provide acceptable simulations of a particular place and its unique hydrology. It will be argued that there are many different parameter sets that will be compatible with what it is possible to know of a place (the equifinality problem) and that the application of hydrological models must therefore be associated with an assessment of the predictive uncertainty implied by these multiple possibilities.

ASSIMILATION OF REMOTE SENSING DATA IN SVAT MODELS : DESCRIPTION OF THE ALPILLES EXPERIMENT AND FIRST RESULTS

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The Alpilles experiment was designed : (1) to test water and heat flux models in the soil-vegetation-atmosphere continuum (SVAT model) over long period in the case of cultivated fields; (2) to draw and test different schemes of remote sensing data assimilation to infer the evapotranspiration and the soil water balance. The experiment was conducted during the October 96-December 97 period near Avignon. Six fields were instrumented on the main crops of the area (wheat, sunflower, alpha-alpha) to follow heat and water fluxes, and the soil water balance. Concurrently, remote sensing observations were performed in the different wavelength regions from aircraft platforms. The data were regularly collected through the experimental period over an area of 5km by 5 km. Acquisitions of the different existing satellites (SPOT, ERS, RADARSAT, ATSR) were done over the area. First results are presented. The variability in soil properties in the area is presented. The soil hydraulic properties were measured using different methods and the results were compared. Evaporation fluxes measured from the differents fields were compared and related to thermal infrared and radar observations.

COMPARED SENSITIVITY ANALYSES OF A FULLY-DISTRIBUTED AND OF A SEMI-DISTRIBUTED HYDROLOGICAL MODEL FOR A SAHELIAN WATERSHED.

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A fully-distributed, physically-based hydrological model has been established to represent the runoff to an endoreic pond over a 2-km² pilot watershed in the sahelian region of Niamey (Niger), using the *r.water.fea*, GIS-integrated model. The objective is to simulate the renewal of water resources in the area, made of a myriad of such small-size collecting ponds and of the underlying unconfined aquifer which is itself recharged via the ponds. This requires adequate representation of the interactions between runoff production from encrusted soils and losses in the conveying ravines. In order to facilitate the extension of this model to a relatively homogeneous area of about 1000 km² encompassing the pilot watershed, a simplified, semi-distributed model based on similar modeling principles is being developed, and compared with the first model. This paper presents the behavior of the two models when varying model parameters and space/time resolutions. The upscaled model will be used for the purposes of two PNRH (*French National Programme in Hydrology*) -sponsored projects, entitled:
- "*Impact des fluctuations pluviométriques sur la réponse hydrologique en zone sahélienne étudié à parti d'observations et de sorties de MCGA* ", and:
- "*Approches hydrodynamique et géochimique du fonctionnement hydrologique dans la dépression piézométrique fermée de Dantiandou* ".

WATER UPTAKE BY PLANTS IN DIFFERENT ENVIRONMENTAL CONDITIONS

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The objective of this study is to determine the depth of the active root uptake in the soil layers as a result of the climatological and geografical situation of the observation site (hydrological aspect).
Measurements of $^{2}H/^{1}H$ or $^{18}O/^{16}O$ ratios of plants sap can be used to determine the source water for a plant. Since no isotopic fractionation against isotopic formes of hydrogen and oxygen occurs during soil water uptake by roots, the relative dependence of plants upon different water sources in the soil can be assessed by comparing the isotopic composition of stem water with that of potential water sources in the soil. These results enhance our understanding of soil - root interactions and will contribute to models ecosystem functioning.

TRANSPORT AND RETENTION OF CLAY PARTICLES IN FINE POROUS MEDIUM : EXPERIMENTAL AND THEORETICAL APPROACH

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The transport of solid particles in porous media is involved in many research domains : colloid-facilitated transport of contaminants such as radionuclides, decline in productivity of wells, alteration of media permeability, water treatment... The present work concerns experiments : using laboratory columns, suspensions of Ca-smectite have been injected into a fine siliceous porous medium. The main objective was to study the transport and retention of clay particles according to variation of many parameters : flow rate, column's length, ionic strength and valence of ions. An increase of particles removal from suspension is observed with increasing ionic strength and decreasing flow rate. For flow rate and ionic strength parameters, experiments allowed to determine critical values above which the retention of particles is strongly increasing. A resolution method, based on an enhanced particle tracking, is used to reproduce experimental breakthrough curves. Different models are tested, all based on the classical advection-dispersion equation in which sources term are included, using kinetic parameters.

IS THE EVAPORATION FROM PHREATIC AQUIFERS IN ARID ZONE INDEPENDENT OF THE SOIL CHARACTERISTICS ?

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Evaporation is the main outflow process from phreatic aquifers in arid zones where it might reach the maximal flux all year round. Arid climatic conditions are not the limiting factor of evaporation from aquifers whose piezometric level is at least 0.3 m below bare soils. After hydraulic studies of soils, the dependence of the evaporation on the soil characteristics has been established and admitted. After interpretation of isotopic profiles of the unsaturated zone, the approximately twenty available data of quite different soils from very distant places show that evaporation seems to depend only on the piezometric depth. This apparent contradiction may be explained : (1) high dependence of evaporative flux on soil characteristics had been concluded on the base hydraulic conductivities determined for suction of less than 150 m that is insufficient, (2) near soil surface suction reaches values of about 5000 m for which the hydraulic conductivity equals the equivalent vapour conductivity that varies weakly for large type of soils and temperature ranges, (3) the fitted curve of evaporation determined on the base of 21 isotopic profiles, with q in mm yr^{-1} and z in m, is : $q = 71.9\ z^{-1.49}$, (4) after hydraulic conductivity data recently published for a loamy soil up to a suction of 1000 m and for a sandy soil up to a suction of 2500 m, the upper and lower bounds of this relation are : $28\ z^{-1.8} < q < 205\ z^{-1.6}$.

COUPLING OF A HYDROLOGIC PHYSICAL BASED MODEL (TOPMODEL) WITH A SNOWMELT ROUTINE (SAFRAN-CROCUS) FOR DISCHARGES SIMULATION OF A FRENCH ALPINE CATCHMENT.

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Within the framework of the PNRH, this project aims at understanding the flood generating mechanisms on a temperate alpine catchment (Sarennes river 28.5 km^2). A physically based hydrologic model, TOPMODEL, is coupled with a snowmelt routine (SAFRAN-CROCUS) including both a data assimilation scheme and a melt model providing spatially distributed melt layer at ground level. The discharges modelling is performed with two spatialisation levels of the snowmelt input provided by the snowmelt routine for different elevations intervals and seven different aspects: First, the lumped version of TOPMODEL process any single data input (either rainfall or meltwater) at each time step as uniform over the whole catchment. Secondly, TOPBAND, a semi-distributed version, split the catchment into a kind of jigsaw where only those pieces receiving melt water are processed, therefore taking into account the fluctuation of the snowline and 0°C isoline.

EFFECTS OF SOIL MICROTOPOGRAPHY ON OVERLAND FLOW AND INFILTRATION IN CULTIVATED PLOTS

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The spatial and temporal distribution of soil surface microrelief is one of the key variable influencing overland flow hydraulics and soil erosion. However knowledge of these space-time dynamics remain poor. The goal of this paper is to better characterise the effects of the evolution of microtopography on the distribution of the flow depths, the magnitude and direction of flow velocities. A two dimensional model based on an explicit finite difference scheme coupling overland flow and infiltration processes for hillslopes represented by topographic elevation and soil hydraulics parameters is used to simulate runoff production and transfer under contrasted soil relief conditions. A real field application in a groundnut plot in southern Sénégal is presented and first result are discussed with implications for the role of microrelief in controlling surface runoff and soil erosion in cultivated field.

HYDROLOGICAL MODELLING OF RHÔNE BASIN

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The goal of the French program GEWEX/Rhône is to develop a method to estimate the hydrological budget of a large European river using existing datasets. The Rhône basin (86500 km^2) has been chosen because it presents several interesting features : a strong climatic contrast between the north part (under oceanic influence) and the south part (under Mediterranean influence), a heavy influence of the snow on the Alps and Jura mountains rivers flows and a limited underground domain. The adopted methodology is based on the use of 4 « linked » models : the meteorological analysis system SAFRAN generates the relevant meteorological parameters with the hourly time step at 8 km resolution by using the observations of Météo-France. The surface energy and mass fluxes are calculated by ISBA, the land surface scheme developed by Météo-France. It uses precise maps of the soil texture and the vegetation cover (resolution of 2 km). The snow covered surfaces are specially treated by using Crocus, a physically-based model originally developed for operational avalanche risk forecasting. Lastly, the hydrological model MODCOU calculates the water outflow in the soil and the river flows with a variable spatial resolution depending on the topography (between 1 km and 8 km).The results obtained with this rather sophisticated tool are presented for a 15 years simulation (from 1981 to 1995) and compared with a rich set of flow measurements (86 hydrographical stations). Water and energy budgets are studied for some sub-basins of the domain in the light of inter-annual variability. A particular attention will be paid to the snow cover simulation and its major influence on the alpine rivers flow

VARIABILITY OF NITRATE IN FISSURE GROUDWATER AND CONSTRAINT FACTORS (GEOLOGICAL, REDOX, HYDRODYNAMIC)

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In Brittany, impropitious qualitative and quantitative aspects of groundwater are strong economics and health limitations. Hydrogeological studies of fissured aquifers are then necessary in order to limit or to solve these problems. So, a study about organization and processes in a fissured hydrogeosystem is in course in the Kerharo's river basin (Finistère, France), underlain by the Brioverian sandstone schists. Observations and measurements have been made from the river basin scale (50 km^2) to the experimental area scale (0,35 km^2) corresponding to a polyvalent farm (Kerveldreach) on a simple morphological versant of 4 to 5 % declivity, where 53 water points (17 drilled holes, 1 dug well, 9 auger holes, 25 drains, 1 spring) can be used. A plurimethodologic approach, using geology, geophysic, hydrodynamic and hydrogeochemistry has allowed us to know some aspects of the aquifer geometry (heterogeneity, anisotropy, connectivity, inner limits), in order to evaluate the hydraulic parameters ($T=10^{-5}$-10^{-4} $m.s^{-1}$, $S=10^{-4}$-10^{-3}), and mainly, to show the hydrogeochemical processes of groundwater. These are dominated by redox conditions responsible of a vertical zonation, with an upper nitrated oxidizing zone separated from a reducing and denitrificated ferrous iron (up to 10 $mg.l^{-1}$) zone where organic matter, sulphide and ferrous iron are oxidized by oxygen of the nitrates. The thickness of the superficial zone (less than 50 meters) is strongly controled by hydrodynamics. This hydrogeochemical zonation might be extended to all the Brioverian and perhaps to other formations of "Massif Armoricain".

MODELLING THE SURFACE PROCESSES IN MIDDLE MOUNTAIN CONDITIONS : COMPARISON AND SENSITIVITY STUDIES.

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Four soil-vegetation-atmosphere transfer (SVAT) models of increasing complexity have been tested in a temperate middle mountain environment (Ringelbach catchment, Vosges mountain, France) : a very simple soil water budget using Penman potential evapotranspiration ; the Earth model (Choisnel, 1985) develloped for agrometeorological applications, using Penman-Monteith evapotranspiration and two soil storages ; the ISBA parameterization (Noilhan and Planton, 1989) used by Météo-France in numerical weather prediction models ; the physically based SiSPAT model which represents all the water and energy processes with equivalent degrees of simplification.
Rather satisfactory simulations have been obtained using these models over 8 years at four sites of different slopes and exposures within the small Ringelbach catchement. Sensitivity studies, using Monte-Carlo method, have been performed. Soil parameters greatly influence the results for all the four models ; Earth results are more dependent on the albedo and plant structural resistance values, ISBA and SiSPAT results on the leaf area index.

COUPLING SVAT MODELS WITH MULTISPECTRAL RADIATIVE TRANSFER MODELS INTO THE CANOPY. FIRST RESULTS WITH THE ALPILLES EXPERIMENT.

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In order to retrieve biophysical variables such as soil moisture and vegetation structure from multispectral remote sensing observations, a SVAT model has been coupled with Radiative Transfer Models into the Canopy (MTRC) in the visible, thermal infrared and microwave domains. We are thus able to simulate the radiative, energy and hydrological exchanges in the Soil-Vegetation-Atmosphere system. The first step is to use the simulated directional reflectances, temperatures and backscattering to test, with the Alpilles data, the behaviour of the direct coupled model, and the second step is to study the possibilities of coupled inversion. The MTRC used in the reflective optical domain (visible and infrared) is an improved version of SAIL model (Verhoef, 1984), the microwave model is derived from Wigneron *et al.* 1993. The radiative processes into the canopy in the visible and thermal domain have been carefully studied to include both multiple reflections between the soil and the vegetation, and the cavity effect (absorption of radiation into the vegetation). The explicite dependence upon vegetation structure (LIDF and leaf mutual arrangement) has been introduced in both SAIL and microwave model. The first results using the directional aspect of the coupled SVAT-MTRC, at field scale, are related with the retrieval of soil and foliage temperature using two directional measurements of brightness temperatures over the Alpilles fields.

HYDROLOGICAL STUDY OF THE RHONE BASIN

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The paper describes the GEWEX Rhône program concerning the modelling of the Rhône basin ($86496 km^2$) with a distributed hydrological model. The hydrological modelling of the Rhône basin is very interesting because of its complex orography, the climate variability and the importance of the snow and ice components. The different steps of the modelling program will be discussed. In this application, detailed soil and vegetation maps have been used to describe the surface. The atmospheric forcing (i.e. temperature and humidity at 2m, wind speed at 10m, atmospheric and solar downward radiation, surface pressure and precipitation) has been reconstructed using a dense network of surface atmospheric stations. Satisfactory results are obtained for the year 87-88. The simulation of the different terms of the water cycle shows a large spatial variability of annual evaporation and runoff across the basin. The ratio of evaporation over precipitation is around 60 % in the area of low orography and close to the Mediterranean sea. The Alps are characterised by very high values of runoff (more than 80 % of precipitation) and weak annual evaporation because of the presence of snow.

DISSIPATION OF MOMENTUM DURING FLOW IN FIELD SOILS

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The balance of momentum is one of the fundamental laws of conservation during flow. Its consideration in soil hydrology leads to a dynamic approach to flow and may explain a host of flow phenomena. In principle, energy consumption during flow in unsaturated soils is either due to the diffusion of capillary potential or due to the dissipation of momentum. At the macroscopic scale of soil cores or profiles, however, this clear distinction is no more possible because both processes may occur simultaneously at various sites at the scales of pores, leaving a considerable range of overlap between the two concepts.

Momentum of flow in soils is estimated either from drainage flow at some depth or from rapid soil moisture readings, for instance, with TDR-equipment. The same principles lead to the estimation of the dissipative flux. In-situ sprinkling experiments thus reveal the extent of macropore systems in field soils and their minimum volume at the location of soil moisture readings.

The method will be presented and examples of momentum dissipation, water flow and particle transport will be discussed.

LARGE SCALE EXPERIMENT ON CONTROLLED AQUIFER POLLUTION BY TRICHLORETHYLENE

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The problematic of groundwater pollution by chlorinated solvents concerns many aquifers in industrialized countries. The French-German Institute for Environmental Research (IFARE) realised a great device called "SCERES" (Site Contrôlé Expérimental de Recherche pour la Réhabilitation des Eaux et des Sols). This buried basin, built with reinforced concrete is 25m long x 12m wide x 3m deep. The main porous medium is a sand with a hydraulic conductivity of 8.10^{-4} m/s. Experiments are conducted in order to approach in real situation and controlled conditions several aspects such as multiphase migration phenomena in aquifers and interactions between immiscible phases in different soil compartments (vadose zone, saturated zone). Furthermore numerical models of the multiphase flow will be used. After a first period of laboratory experiments, 9 liters of trichlorethylene (TCE) were infiltrated on SCERES with a special set-up to regulate injection and to avoid evaporation. With this system, TCE was injected 35 cm under the soil surface at 1.8 m above the water table. The measurements permit to quantify the evolution of the impregnation body, to determine the pollution transfer by volatilisation in the unsaturated zone and the transport of dissolved traces in water flow. The data from these controlled site experiments will allow to obtain a mass balance.

MODELLING THE INFLUENCE OF A MULCH ON THE WATER AND ENERGY BUDGET OF A FALLOW LAND

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In order to validate land surface schemes used in atmospheric or climatological models, a data set including climatic data, surface fluxes, surface humidity and temperature, soil temperature, soil water content and pressure, biomass monitoring was collected during three years (1995-1997) on a fallow site located in the south-east of France. On June 2 1995 the farmer cut the grass cover and increased the mulch layer thickness. The water and energy budget of this field was simulated with the SISPAT SVAT model (Braud et al., J. Hydrol., 1995), a model of coupled heat and water transfer in the soil-plant-atmosphere continuum. It was found that the model was not able to reproduce the soil temperature and the surface soil moisture correctly. The temperature amplitude was overestimated and the surface soil moisture, which remained high even after a long drying period, was underestimated. The model was modified to account for the mulch layer, where water transfer in the vapour phase is very important. The simulation with a mulch layer of 5 cm was able to predict the lower amplitude of soil temperature and to maintain soil surface humidity during all of the simulation. These results showed that the role and characterisation of the surface layer must be conducted carefully in order to correctly model the annual water and energy budget. There is also a need for improved experimental techniques to derive the thermal and hydrodynamic properties of a very thin surface layer.

STUDY OF NON LINEARITIES IN KARSTIC SYSTEMS USING WAVELET TRANSFORM AND MULTIRESOLUTION ANALYSIS

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Karstic aquifers are caracterized by great dynamical heterogeneity with several response time scales which implies non linearities in their behaviour and so difficulties in their simulation. Our purpose is to apply new methods of signal analysis in order to relate precipitations and discharge rate of karstic springs. These signals are two non gaussian and non stationnary series sampled at different rates. So, we need a better knowledge of input and output signals and especially a dual time-frequency or time-scale vision. The wavelet transform was choosen since it permits, under some conditions, to efficiently decompose and synthesize such signals. There are two different kinds of wavelet transform : the continuous Morlet wavelet transform which does not use an orthogonal basis and the multiresolution approach based on orthogonal basis constructed with a dilation equation. After some tests using synthetic time series, we present some results concerning different kinds of karstic basins located in the South of France, which have been studied for many years. The wavelet transform allows us to present a classification of those aquifers from fast response to diffuse response similar to one obtained by Fourier classical analysis but more synthetic. Perspectives of this work are (i) to perform cross analysis with the help of the wavelet transform and (ii) to propose a generalisation of the transfer function. The following step will be the implementation of a non linear optimisation of the parameters of this function to predict outflow correctly, especially concerning peak rates and low rates.

THE CONTRIBUTION OF EVAPOTRANSPIRATION TO THE ENRICHMENT OF ^{18}O AND ^{2}H IN THE WATER VAPOR UNDER NATURAL CONDITIONS

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The diurnal variation of isotopic compositions of water in the soil-plant-atmosphere continuum was carry out during a typical summer day. This study was performed on a spruce stand located in Strengbach catchment (Vosges, France). With stable isotope measurements, microclimatic and ecophysiological parameters were used in an integrated approach to understand processes involved during the water transfer.
The origin of the water taken up by spruce (*Piceas abies*) was determined by comparing oxygen-18 contents in tree sap and soil water: the mean root water uptake was active in superficial soil layers. In addition, the isotopic composition of sap water shows no temporal evolution.The $^{18}O/^{16}O$ ratio of needle water increases during the morning until the early afternoon and, then towards evening the $^{18}O/^{16}O$ ratio decreases rapidly.The isotopic enrichment of atmospheric water vapor in and above the canopy was maximun toward 15h00 (UT). After 15h00, the isotopic signature of atmospheric water vapor began to decrease. This evolution could be related to the decrease of the transpiration flux. The used of a single two-component mixing model allowed to estimate that the atmospheric water vapor at 15h00 was composed of about 42 % of transpired water vapor.

TESTS OF A NEW TDR-METHOD TO MEASURE SOIL WATER-CONTENT PROFILES.

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A new method – called TDR-SSI for « Spatial Signal Inversion » – has been developed to measure water-content profiles in soils. First, one single TDR signal is taken on a probe which length (1m maximum for the moment) determines the depth of the zone that will be explored. Then, the dielectric constant profile is calculated from this signal by inversion and renormalization. In order to allow a cross-comparison of TDR-SSI versus other methods, several experimental stations in France have been equipped with such probes and at least one other measurement technique : neutronic, TDR tube TRIME ™, gravimetric... The first results show a fair agreement when the TDR signal remains « useable ». Difficulties appeared in two of our tests, due to high losses by electrical conduction in the soil. In the first case, on alluvial flooded forest in the Rhine Valley, water content and solutes concentration were very high. In the second case, on one site of the « Alpilles experiment », the high clay content of the soil is probably to be considered. Despite this conduction problem, TDR-SSI appeared to be convenient and accurate enough for most applications in soil physics. Nevertheless, technical solutions have to be found to keep the method useable in every soils or for greater depths. Fields tests are still going on to refine these first conclusions.

ORIGIN OF SALTY WATERS FROM BOLIVIAN ALTIPLANO: CONTRIBUTION OF THE SR ISOTOPIC DATA AND GEOCHEMISTRY.

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The aquifer of the Bolivian central Altiplano displays geographical sectors with distinct salinities (with Cl concentrations varying from 0,2 to 150 mmol l^{-1}). On basis of previous extensive hydrological studies, 33 superficial and underground waters were sampled and major, minor and Sr isotopic analyses were realized on these samples. The R=87Sr/86Sr, U/As ratios, and Na, Cl concentrations allow to distinguish four distinct groups among the water samples. Groups I and II display respectively low (Cl ranging from 0,2 to 8 mmol l^{-1}), and medium (Cl ranging from 4,5 to 25 mmol l^{-1}) salinities. They are clearly associated with water supplies to the aquifer from the West and North side respectively. Group III shows very high salinity (Cl and Na range from 350 to 2000 mmol l^{-1}) and is associated with solutions related to intrusive dacites. The salty waters which locate at the South of the aquifer (displaying a high salinity with Cl ranging from 15 to 150 mmol l-1) gather in the group IV. This latter group shows R and As/U ratios intermediate between the values displayed by groups I and II. Data analysis supports a model in which : (a) group IV waters derived from a mixing of group I and II waters, (b) subsequent evaporation processes lead to their high salinity.

CHARACTERIZATION OF WATERS FROM BOLIVIAN ALTIPLANO: GEOCHEMICAL MODELLING APPROACH

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The groundwaters analysed for major (and trace) elements on the Bolivian Altiplano site allows to characterize different type of solutions. From data on temperature, pH and aqueous concentrations of elements (Ca^{++}, Mg^{++}, Na^+, K^+, HCO_3^-, Cl^-, SO_4^{--}, NO_3^-, $SiO_{2(aq)}$) the calculations of speciation have been carried out with a geochemical code based on thermodynamic laws. The rain waters are frequently diluted with a total charge varying from 6 to 15 mg/l (Patacamaya, Chilahuala, Chiquichambi, San José). These one are undersaturated with respect to quartz (SI from -0.9 to -3.7) and calcite (SI from -3.0 to -4.7). Some rain waters (Huaylla Marca, Colque Amaya) are oversaturated with respect to quartz (SI from 0.15 to 0.64) with a total dissolved charge of 120 mg/l (anomaly due to the wind action). All surficial waters and groundwaters (130 samples analysed from campaigns of 1993, 1994 and 1995) are oversaturated with respect to the polymorphs of silica (quartz, chalcedony...) and to the dolomite and calcite. Some solutions (Huari, Umala, Unapata, San José,...) are saturated with respect to antigorite and chrysotile (serpentine group) resulting of the weathering of olivine and pyroxene from basic-rock underground. The sepiolite (Talc group) can be precipitate in these waters containing Ca and Mg in high concentrations. The characterization of the origin of the waters mineralization on the Bolivian Altiplano site can be described from a geochemical approach.
This work is included in the Programme of Hydrology Research developed in France (PRH).

COMBINED USE OF HYDROLOGICAL AND HYDROCHEMICAL DATA TO MODEL THE ROLE OF THE WATER TABLE IN NITRATE TRANSFER

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The 5 km^2 experimental catchment is located in West of France (Naizin, Brittany). The soils are developed into a loamy material over weathered Brioverian (Paleozoic) schists. The mean concentration of the streamwater is around 15 mg.l^{-1} of N-NO_3 due to intensive farming. The concentrations are the highest in winter, and very low in summer. A transect of four piezometers was set up according to the slope direction. The water table depth was monitored during one year with a time step of 15 mn. The chemical variations were measured fortnightly in the piezometers and in the stream for different elements and isotopes. The water table depth in the slope is of a few meters in winter and varies rapidly and importantly during the rainfall events. At the bottomslope, the water table is near the soil surface and does not vary much. A chemical decreasing gradient from upslope to the bottomslope is observed for both major (e.g. NO_3, SO_4, Cl) and trace elements (e.g. Sr, Ba). The variations of the concentrations in time are moderate, except at the footslope. These data are used to model water and nitrate transfer within the hillslope. The objective of the modelling work is to precise the time characteristics of the transfer according to the location in the slope, and to test the hypothesis of a winter nitrate destorage due to the fluctuations of the water table that may intercept the percolation from the vadose zone.

VEGETATION DYNAMICS AND THE WATER AND CARBON DIOXIDE FLUXES

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Water and carbon dioxide fluxes in the soil-plant-atmosphere continuum widely depend on the vegetation. A study was conducted on a set-aside field (Murex research program) during the 1997 growing season to determine the seasonal and diurnal dynamics of the vegetation features as influenced by environmental conditions. Stomatal conductance and water potential were measured on leaves of major species from early spring to autumn, along with biomass and LAI dynamics of the field vegetation. Carbon dioxide flux were measured at the canopy level during the dry summer period. (1) The set-aside field plant species exhibited low stomatal resistance, indicating their potential ability to maintain high gaz fluxes. (2) Some differences between coexisting species occured for diurnal variations of stomatal conductance and water potential. (3) The diurnal variations of stomatal resistance and water potential were different for low VPD and humid soil conditions on one hand, and for high VPD and dry soil conditions on the other hand. (4) The set-aside field appeared to be a carbon source during summer due to high plant and soil respiration rates. These data were used to model the fluxes over the field for 2 years.

RENEWAL AND DEVELOPMENT OF THE HYDROLOGICAL REGIME REPRESENTATIONS : CONCEPT, VARIATES, MODELS, MAPS.

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Since a lot of years, several hydrologists observed a need for reconsidering our position on the hydrological regime concept. Among the reasons, three can be underligned : (i) the recent and large, but also diversified and complex, progresses made on the understandment of the basic hydrological processes, lead to a corresponding need of synthesis ; (ii) the arising of a progressively better taking in account of the hydrological knowledge for water, river, flood plain and basin management, lead to a need for hydrological representations which are relevant for long term and sustainable stakes ; (iii) the development of an integrated management of water bodies and water concerned populations (human societies and biocenoses), in a changing environment, lead to a need for interfacing the hydrological cycles and processes with a lot of other behaviour's scientifical representations. Facing such increasing needs, the old regime concept and representations appear clearly as under-developed, and frequently even no more adequate or relevant. So, a team inside the french PNRH was requested to start a basic research on regime concept, variates, models and on any scientifical synthesis representation able to adress these new stakes. The target is double : (i) develop a synthesis based scientifical knowledge, through new modelization of regimes including short durations, respecting the processes time scales, etc..., and able to represent influences and trends ; (ii) strenghthen the scientifical basis of water and water bodies integrated management. The first step, which is on-going, focusses on the time scales aspects for a local regime, which appear as deeply under-developed and thus needing numerous complements or redefinitions. A second step will further adress the space scales problems, and beyond the classical spatial variations, will focuss on several space scale effects, largely underestimated when not quite ignored until now, like the non-additivity of several hydrological regime variates when upscaling (downstreaming) them, which induces very peculiar problems of huge importance, as for mapping, or for water resources assessment.

THE NUMERICAL MODELLING OF THE INSTABILITY OF INFILTRATION IN A ROCK WITH HETEROGENEOUS TEXTURE

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The permeability of the rock is a critical property, to describe the fluid flow and the associated mass transfer in the aquifer layers. The permeability and the flow are closely related by a non-linear feed back, through the dissolution and precipitation of minerals in the rock. This is the result of the coupling between the evolution of the texture, the porosity, the permeability, of the rock and the water/rock chemical interaction. Our numerical modeling focuses on the physical mechanism involved in the growing of the instability of the reaction front in the matrix, at the scale of the instability. Our study describes the growing of the worm-like instability, in a rock in which the texture is initially heterogeneous. It illustrates the characteristic behavior of the fingering when it is controlled by the advective transport of the undersatured fluid. We show that initial heterogeneity favors the fingering, which as a result develops faster. When the dissolution is controlled by the transport, not only the magnitude of the flow velocity but the flow pattern is critical for the evolution of the shape of the reaction front, during time. We find that the correlation between the shape of the infiltration instability and the pattern of the initial heterogeneity depends on the ratio of the size of the heterogeneity and the size of the resulting fingers.

GEOCHEMICAL CONTRIBUTION TO MESOSCALE WATER PATHS : MAJOR, TRACE ELEMENTS AND Sr ISOTOPES APPLIED TO THE PEYNE WATERSHED (HERAULT, FRANCE)

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How can geochemistry contribute to mesoscale hydrological modeling? In order to answer this question a watershed with contrasting lithologies was chosen. As a first stage a geochemical search had to be done to identify reliable tracers for the identification of water paths in a small watershed (e.g. among the major, trace elements, Sr isotopes which are often used in the study of surface water). Only geochemical data are given here. The study focuses on 2 geologically and hydrologically independent, distinct parts of the Peyne watershed (70 km^2). The different lithologies (15) were geochemically characterized by leaching experiments (immersion) with deionized water. One of them was also studied by percolation on a column for comparison. Each soil is clearly identified by its specific concentration ratios and Sr isotopic signatures. Three sampling campaigns were performed (2 low flows, 1 high flow) on very small brooks draining monolithologic parts of the basin. The dissolved loads were compared with rock endmember leachates. Both low flow campaigns present remarkably stable signatures, whereas high flow data are significantly different.

ELECTROKINETIC MONITORING OF WATER FLOW IN LOW CONSOLIDATED MEDIUM

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This study was performed for the PNRH program on geophysical methods used to monitor the subsurface fluid flow. In order to have a better understanding of electric and magnetic measurements performed in the field and that are thought to be induced by water flow at shallow depth, we performed laboratory measurements. Water flow in porous medium is known to induce electrokinetic phenomenon and to generate an electric field. We measured the streaming potential induced by water flow in low consolidated medium as sand, along a vertical column of 1 m height and 8 cm diameter. The electric potential was measured by 10 impolarizable electrodes and the water pressure was measured at the same place by 10 pressure sensors.
The low consolidated medium is thought to be representative of the uppercrust and the knowledge of its electrokinetic properties is required in order to find the relation between the electric field and the water flow in the purpose of water monitoring by electric method.

MONITORING ISOTOPIC EXCHANGE WITHIN A FOREST STAND: RELATIONSHIPS BETWEEN H_2O AND CO_2 ISOTOPIC SIGNATURES

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Stable isotopes are used to characterize H_2O and CO_2 exchanges between biosphere and atmosphere, through the isotopic exchange processes in the continuum soil-plant-atmosphere. The isotopic exchange between liquid water and CO_2 inside leaves could be used to determine the CO_2 exchange processes, from the relationships between $H_2{}^{18}O$ and $C^{16}O^{18}O$. In order to determine this relationship in natural conditions, an experience was carried out at an INRA experimental place in the Landes forest. In this 25 years old pine plantation, measurements of water vapour and CO_2 isotopic compositions were performed through a nycthemeral cycle at 11 different heights. At the same time, we characterized the isotopic compositions of water in different biospheric compartments and recorded CO_2 fluxes above and under the canopy using an eddy covariance method. From the leaf water and water vapour isotopic compositions, the isotopic composition of the water under evaporation within the leaf is calculated by the evaporation isotopic model. Isotopic compositions of leaf water and water under evaporation shows a similar evolution during the day with a maximum at the end of the afternoon. The isotopic signature of the CO_2 at the tree level follows the same pattern what shows that foliage water controls this signature and not the mixing with regional air. Moreover, the high isotopic composition of the CO_2 observed implies an isotopic exchange with the most enriched water in the leaf, i.e. the water under evaporation, even during the night.

FIELD MEASUREMENT OF SOLUTE TRANSPORT PROPERTIES OF SOIL USING A TENSION DISC INFILTROMETER AND ^{18}O

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Natural tracers (as ^{18}O for example) are good tools for the quantification of run-off and infiltration, but their transfer through the vadose zone must be described. By using the tension disc infiltrometer along with conservative tracers, a simple determination of both unsaturated hydraulic characteristics and solute transport parameters is possible. The unsaturated hydraulic conductivity, K, and the effective mean pore size, λ_m, are obtained using the transient analysis of the 3D infiltration from a disc infiltrometer, and a new approach is proposed for the identification of the dispersion coefficient, D, and the mass transfer coefficient, α. The combined use of the experimental values of C^* (the concentration of solute in the soil) and θ (the total volumetric water content) beneath the disc with an analytical solution of the solute transport provides estimates of D and α. The spatial distribution of θ and C^* shows the highly preferential flow under the disc. The evolution of the transfer parameters was investigated as a function of the supplied water pressure head. For both the water flow and solute transport, results show an abrupt change near saturation, as the consequence of a transition from a capillary-dominated to a gravity-dominated flow.

WATER MOVEMENT ~~FROM SOIL TO ROOT~~ INVESTIGATED THROUGH SIMULTANEOUS MEASUREMENT: SOIL WATER POTENTIAL, ROOT DISTRIBUTION AND HYDROLOGICAL TRACERS.

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Water flow in the soil-root-stem system was studied in an alluvial flooded forest ecosystem under natural conditions. This study was undertaken to identify the origin of water taken up by trees in a system where the groundwater is at a depth of less than 1m. The root distribution of the three species was analysed. The isotopic signal (^{18}O) of soil, root and stem was monitored for *Quercus robur* and *Populus alba*. We attempt to establish a relation between the root density and the isotopic composition of water of stem and soil at different depths down to the groundwater level. The root density of the oak was maximal at a depth between 0.20 and 0.60 m whereas the roots of the ash colonize the surface horizon (0-30 cm). Isotopic signal of stem water is constant along the day, which leads to suppose that the absorption of water by plants is realized at a relatively constant depth. From the comparison between isotopic composition of water in the soil and that of the plant, we conclude that the water is absorbed from the layers between 0.40 and 0.60 m deep, which is in good agreement with the distribution of oak roots. The surface layers and the capillary zone do not participate to the water uptake by the oak.

TRANSPORT PARAMETER IDENTIFICATION : APPLICATION OF THE SENTINEL METHOD

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Predicting the future extent of a pollutant plume or testing several remediation techniques needs transfer modeling. Missing pollution parameters, such as exact source location, pollution mass flow and dispersivity, can be estimated with a parameter identification, such as the Sentinel method. This method was applied to groundwater pollution parameter identification.
Two different algorithms to apply the Sentinel Method can be used : the direct or the iterative one. First the inverse problem was solved in the linear case to estimate pollutant mass flow and/or initial concentrations. The direct method was compared with the more classical least squares methods. Then the non-linear case was studied to recover the source coordinates and/or the dispersivity.
Numerical tests were conducted on the Rhenan aquifer south of Strasbourg. The Sentinel method recovered mass flow with respect to the time and pollution source location, first separately and then simultaneously, for different cases. Results show how estimation reliability depends on available observations. More generally, these tests can help choosing relevant observation points location and pointing out the advantages and limitations of the Sentinel Method for groundwater pollution problems.

DYNAMIC DRAINAGE AREA AND SPATIALLY VARIABLE PRECIPITATION INPUTS WITHIN THE TOPMODEL FRAMEWORK.

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The recent widespread availability of digital terrain data has resulted in an increasing use of variety of hydrological models of different degrees of complexity. The physically based distributed TOPMODEL framework has been shown to be able to predict, with a reasonably good quality, the process of runoff on saturated areas, that is the predominant process for flood generation on catchments with significant topography. It is based on the concept of topographic index of hydrological similarity, which can be roughly expressed as the ratio between the upslope drainage area and the local slope. In this presentation we explained how we relax some limitations of the model such as the assumption of a non spatially variation of the recharge of the water table and the use of a map of drainage area that is usually assumed to be constant in time. This work and the correspondence we make with previous fields and numerical studies done in our team conduct us to submit a scheme of hillslope behaviour with two types of lateral drainage with different dynamics, one for the runoff process and one for the deeper hillslope water table. We hope this extends the applicability of the TOPMODEL framework for wetting up or drying periods, and will be a efficient numerical tool to help us in identifying at which time and space scale the hydrological systems are sensitive to spatially variable precipitation inputs.

SIMULATION OF CONVECTIVE RAINFALL OVER URBAN AREA

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A high resolution 3D mesoscale meteorological model has been used to simulate convective rainfall over an urban catchment near Paris. Subsequently, an urban hydrological model, calculating surface processes as well as discharge processes, has been initialised with the simulated rainfall data. Comparison of the simulation with observed rainfall and discharge in the sewer system show that the coupled system describes qualitatively well the dynamics of the storm. However, quantitatively the meteorological model underestimated the rainfall owing to lower simulated rainfall rates than observed and due to unsatisfactory positioning of the rainfall fields. Sensibility tests performed with the meteorological model indicate that the presence of an urban area in the model domain influences both the rainfall intensity as well as the position of the rainfall field. Therefore the treatment of the lower boundary condition should take into account the presence of urban surfaces in mesoscale meteorological models.

NUMERICAL SIMULATION OF THE MIGRATION OF TRICHLORETHYLENE IN A LARGE SCALE BASIN

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The simulation of 14 liters of trichlorethylene (TCE) released in the vadose zone of the large scale basin SCERES (Site Contrôlé Expérimental de Recherche pour la Réhabilitation des Eaux et des Sols) was studied using two numerical multiphase flow simulators: SIMUSCOPP (developed at IFP) and SWANFLOW (prepared by GeoTrans Inc for EPA). The goal of the multiphase modeling was the description of the potential lateral and vertical extent of the TCE impregnation body and its migration velocity, which depend strongly on the chosen injection flux, the fluid properties and the pore size distribution of the porous medium. The sensitivity of the dominant parameters have been evaluated. The numerical studies showed, that the capillary forces do not increase significantly the lateral extent of the TCE body. However, the estimated residual saturations above and below the water table are considered to be one of the most sensitive parameters. Furthermore, the simulations based on experimental data and theoretical approaches underline the role of the relative TCE permeability on the infiltration velocity and the equilibrium state in the vadose zone. The comparison of the numerical results with the experimental data indicates some differences in the flow behavior which might be attributed to the effect of local heterogeneities (due to filling procedure) in the homogeneous sand of the SCERES basin.

FIELD CHARACTERIZATION OF THE RELATIONSHIP BETWEEN ELECTRIC FIELD AND SOIL WATER FLUX IN VADOSE ZONE

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Due to electrokinetic phenomena, fluid flow in porous material produces electric fields. A field experiment was performed to quantify independantly the soil water movement and the electric field induced by this soil water transfer.
Electrical potential differences between electrodes installed vertically at 4 depths (0.3, 0.5, 0.7 and 0.8 m) were monitored continuously during a ten day period following a rainfall event in a measurement site under natural fallow. Simultaneously, changes of soil water content and of hydraulic head were measured on a daily basis at different depths of the soil profile in the same site . They were analysed to obtain daily values of the soil water flux at the depth z = 0.4m. At that depth the water flux was first oriented downwards (infiltration), then shifted progressively upwards (evaporation). It is clearly shown that there exists a very significant linear correlation between the electric potential gradient at that depth and the value of the flux. Probably due to so called electrode potential, there is a residual potential gradient when the flux is null. In any case the results show how promising electrode measurements could be to infer water circulation in the vadoze zone in terms of both direction and amount of water flow.

TRANSPORT OF HERBICIDES IN RUNOFF WATER IN A FARMED MEDITERRANEAN CATCHMENT

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The Mediterranean climate is characterized by a hot and dry summer where occasional storm events induce erosion and runoff. This induces a high leaching potential of pesticides to surface waters. In 1994 and in 1995 we monitored runoff discharge and concentrations of the two soil applied herbicides diuron and simazine at the outlets of a 91 ha catchment located in southern France and of two field sites - one tilled and one no-till - cropped with vine. Pesticide losses at the field scale depended primarily on runoff volume and intensity. In 1994 despite a time lag of 140 days since chemical application, diuron concentrations in overland flow during the first runoff event exceeded 200 µg L^{-1}. In 1995 a single runoff event carried more than 87 % and 60 % of the respective seasonal simazine and diuron losses, although it accounted for less than 17 % and 7 % of the total runoff volume at the no-till and tilled site, respectively., seasonal herbicide loss during 1995 was 1.71 % of applied diuron and 1.25 % of applied simazine at the no-till site, and 0.68 % and 0.79 % respectively at the tilled site, reflecting differences in runoff volume between sites. At the catchment scale, herbicides losses were almost ten times smaller than at the field scale, due to reinfiltration processes. Event average herbicide concentrations over time followed an exponential decay equation. The decreasing water availabilty with time compared to the herbicide content at the soil surface were assigned to an increasing adsorption with time.

COMPARISON OF MIXING-LAWS MODELS ON SOILS TDR MEASUREMENTS DATA.

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The problem of TDR calibration – relationship between dielectric constant K and water content θ – can be treated using « mixing-laws » models. Generally speaking, these are analytical expressions which relate, in this case, the bulk dielectric constant to the proportions and individual dielectric properties of each phase. They are always established assuming some kind of idealized structure. Numerous models can be found in the literature and some of them – like the « α model », for example – are already used for TDR-calibration purposes. First, in the frame of the effective medium theory, we have defined four main types of models that could be used and we suggest a general formulation for them with only two parameters. Then, a set of natural soils and minerals has been selected and, for each, the K(θ) relation has been measured by TDR on a wide range of water contents. All the models have been adjusted on this database and the errors have been analyzed. At this end of this work, the α model appeared to fit the results slightly better than the others. A estimation formula for the α parameter as function of the bulk density is proposed. To go further than this empirical approach in order to predict the value of α, we have also considered the dispersive behavior of the soil : evolutions of the real and imaginary parts of its dielectric constant versus frequency.

A PHYSICALLY-BASED APPROACH FOR ESTIMATING WATER RETENTION CURVE SHAPE PARAMETER.

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To describe water content transfer, in the unsaturated zone of soils, knowledge of the soil hydraulic properties is required. Different functional relationships can be chosen for the description of : a) the relation between soil water pressure (h) and volumetric water content (θ) and b) the relation between hydraulic conductivity (K) and volumetric water content (θ). Full description of the classical water retention curve, h(θ), and the hydraulic conductivity relation, K(θ), is defined by the knowledge of 5 unknown parameters. Although several methods (in situ measurements, pedotransfer functions) have been described in literature for estimating these soil characteristics, most of these methods rely on statistical regression.
A physically based approach for estimating the shape parameters of water retention curve is presented. Based on the concept of geometrical scaling, the cumulative particle size distribution function is related to the cumulative pore size distribution and subsequently to the main wetting curve. The later function is associated to the main drying curve (condition under which water retention function is usually measured) through the theory of hysteresis. This method was tested successfully on an extensive international database.

HSC1 Special hydrological symposia

02 Dryland degradation in the Mediterranean: threat, processes and mitigation

Convener: Bathurst, J.C.
Co-Convener: Quaranta, G.

DECISION SUPPORT SYSTEM FOR THE AGRI BASIN, ITALY

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The past development of models relevant to the study of desertification has tended to consider the physical and socio-economic controls separately, with little allowance for feedback and interaction between them. Within the MEDALUS project the University of Newcastle upon Tyne is therefore building a Decision Support System (DSS) for the Agri basin (1532 km^2) in Italy. This integrates hydrological, sediment yield, vegetation growth and socio-economic (farmer response) models, and a database containing climate, physical and socio-economic data according to a range of scenarios, into a single tool to aid decision making. Feedback between the models will be primarily output on land use changes (farmer response) from the socio-economic model and water availability and crop yield in return from the physical models. Typical issues which the DSS will address are: the desertification consequences of specified climate scenarios, within a context of fixed agricultural policy (especially crop subsidies); and the sustainability of a land use or agricultural policy for a given climate scenario. The talk will describe the aims, design and future use of the DSS.

MOUND-PLANT ASSOCIATIONS IN A PATCHY MEDITERRANEAN MATORRAL.

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In the Mediterranean region, matorral communities often present a discontinuous cover, where isolated perennial plants alternate with bare inter-plant areas. In such ecosystems, the patchy distribution of the vegetation is usually associated with microtopographic sequences of mounds that develop under isolated plants and break the general slope continuity.
In this study, the influence of isolated plants of three representative species of the Mediterranean matorral (*Rosmarinus officinalis, Stipa tenacissima* and *Anthyllis cytisoides*) on slope microtopography is determined and the processes that take part in the development of microtopographic structures beneath the plant canopy are identified. The influence of slope, plant species and plant parameters on the shape and height of microtopographic structures is also studied.
The results obtained show that plant species and slope angle play both a major role in the shape and height of the microtopographic structures. Plant parameters, essentially roughness, influences highly soil surface rise under plants. Four main processes participate in mound development in the field site: sedimentation, differential interrill erosion, differential splash erosion and bioturbation.

MIXTURE MODELLING METHODS TO ASSESS VEGETATION MULTITEMPORAL CHANGES IN GUADALENTÍN BASIN (MEDALUS-III PILOT AREA, SE SPAIN)

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Spectral Mixture Modelling has demonstrated to be a suitable tool for analysing the biophysical and compositional character of ground surfaces. We have focused both in the so called Spectral Mixture Modelling and in the development of a Non-Linear Mixture Model that describes the reflectance of the canopies from biophysical parameters of vegetation, such as optical properties of soil and leaves, vegetation fraction and canopy structural parameters (LAI, LAD, etc.).
The different modelling procedures provide an immediate computer interpretation of surface composition and have been applied to evaluate the inter-annual changes of the natural vegetation cover types in the Guadalentín Basin, a MEDALUS-III pilot area (SE Spain). A series of six Landsat-TM images covering the period from April 93 to May 94 was employed. The images were radiometrically corrected to guarantee their comparability.
The study shows the influence of the vegetation type (Rosemarinus, stipa, disperse matorral or pine forest) and the altitude, which play an important role in the dynamics of vegetation.

SOIL REHABILITATION WITH ORGANIC AMENDMENT: EFFECT ON SOIL STRUCTURE AND MOISTURE CONTENT

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Soil moisture and percentage of stable aggregates were studied in five experimental plots with single additions of 0, 6, 12, 18 and 24 $Kg.m^{-2}$, respectively, of urban refuse (UR). Plots were located in the S.E. Spain.
One year after addition, the soil moisture increased with the dose of UR, being the differences among the plots statistically significant. Two years after addition, the increase was maintained in three plots with the higher dose and no significant differences were found between the control plots and the lowest dose. Nine years after addition, the control plot showed the highest moisture content decreasing in the treated plots as increasing the dose of UR.
The percentage of stable aggregates also increased with UR dose just after addition. Nine years after, the effectivity of UR showed a decay as regard to the first years but the improvement of soil structure still subsist.
The evolution of soil moisture and the permanence of soil structure improvement might be attributable to the effect of the vegetation grown in the treated plots

A DEAD-ZONE MODEL FOR FLOW OVER ROUGH HILLSLOPES

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The MEDRUSH model, developed within the EU MEDALUS project to simulate desertification for areas of up to 2000 km2, uses a set of hillslope flow strips at its highest level of resolution. Surface Roughness within the flow strip model is represented by cross-slope and down-slope roughness elements. Cross-slope random or regular (plough furrows etc.) roughness elements concentrate flow and sediment transport along depressions, and rougher surfaces generate greater sediment transport. Down-slope roughness elements create closed depressions within random linear flow paths, behind plough ridges and at terrace borders. They are represented as a distributed dead zone of zero flow, using a model which has proved effective in rivers draining areas of up to 10 km2. Above the dead zone, flow is treated as of constant velocity. This model gives a strongly non-linear relationship between mean stage and discharge, but with a constant kinematic routing velocity. Although clearly a simplification, this 2-parameter model of the surface is able to satisfactorily reproduce many of the features of overland flow hydrographs.

EVALUATION, AT MUNICIPALITY LEVEL, OF THE EFFECTS OF DIFFERENT ECONOMICAL ISSUES ON THE ENVIRONMENTAL SENSITIVITY OF MEDITERRANEAN AREAS BY INTEGRATED USE OF ECOLOGICAL AND ECONOMICAL DATA: A METHODOLOGICAL PROPOSAL

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The definition of political support quality and entity as well as the kind of interventions to undertake in the forest and agronomic sectors is based on considerations that badly adapt to the different and diversified agro-forest realities and in other environments located on the Italian territory. This is even more evident in those Mediterranean areas where the fragility of the natural as well as the anthropic pressurised ecosystems would need a keen and adequate evaluation, based on punctual, objective, extensible in time and space, and repeatable analyses, within monitoring projects aimed to analyse and interpretate not only the existing realty, but also the dynamics of the changes in progress. An unbreakable commitment has opened to use evaluation and support systems for decision making capable to efficiently and easily supply not only an exhaustive framework of the different components of the territory mosaic, but also relationships that interact among themselves and above all the effects that different intervention options produce. The present paper at first faces the problems relative to the evaluation of the different sensitivity degrees of the environment in the Mediterranean and in particular in the Agri basin (Italy), by proposing an evaluation system as well as a simulation one of the effects on the level of sensitivity of different intervention options. Successively, the model will be tested through two specific intervention options.

HYDROLOGIC AND SEDIMENT RESPONSES TO NATURAL RAINFALL IN A DEGRADED SEMIARID AREA OF SOUTHEAST SPAIN.

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Soil erosion by water is considered to be one of the most important key degradation processes in Mediterranean environments. A deeper knowledge of this process is essential for planning effective, appropriate soil conservation and water measures in these areas. Two experimental zones (300-750 m^2), representative of an extensive degraded semiarid watershed in the SE of Spain, were selected and monitored during 3 years to provide information on the hydrological and erosional response. A pluviogram and hydrograph recorded at 1-minute intervals were obtained for each storm. Total soil loss was manually collected and particle size of the sediment was analysed in each event. High variability in the response was found between and within areas. Runoff response oscillated between 0.12-8 hours, low threshold of rain necessary to generate runoff and sediment (3.6-6 mm), runoff coefficients of 10% and high sediment production rate (0.08-0.30 $Kg.m^{-2}.year^{-1}$) were the general behaviour observed in the experimental areas. Differences in the soil physical (texture, bulk density, aggregate stability, porosity) and hydraulic properties (hydraulic conductivity, infiltration rate) found between the two areas lead to differences in the runoff, erosion and rainfall relationships in each area and therefore explained the variability in the response. A greater proportion of finer particle in the eroded material compared to the matrix soil indicated selective erosion and transport of finer material in these areas.

THE USE OF MIXTURE MODELS IN LAND DEGRADATION PARAMETER ESTIMATION FOR SURFACE MODELLING

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The Mediterranean climatic conditions and extensive lack of vegetation cover, has resulted among others, in soil being heavily eroded. Erosion is one of the main causes of land degradation and consequently desertification resulting in crop damage, loss of livestock, and even migration from the affected area, to more fortunate destinations. Lesvos is an island lying in the NE Aegean sea. The history of the island has shown that human intervention has set the environment under desertification threat. Research is underway (MEDALUS III project) to collect and study all relevant data for identifying the Environmentally Sensitive Areas, by determining soil, vegetation, climate and management qualities. Thematic Mapper satellite data can seriously contribute in defining ESAs, providing vegetation cover and type, and soil status maps. Instead of any other traditional method for retrieving vegetation and soil status, another approach was adopted by using spectral unmixing. Five pure spectral endmembers were chosen based on the complexity of the land surface components and those were, green and dry vegetation, rock, soil, and shade. All endmembers were selected with no previous knowledge of their spectrum, by applying a PCA analysis to the data. Wet and a dry season images were then linearly unmixed and the resulted proportion maps of the unmixed components were tested for their accuracy with the help of ground reference measurements depicting percentage cover of each surface component.

FIRES, SOIL DEGRADATION AND EROSION IN SMALL MEDITERRANEAN RIVER BASIS

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Organic matter content in soil results from the balance among primary productivity and leaflitter production, leaflitter decomposition, and abduction by rainfall events. The loss of wooded areas because of unwise management or natural accidents can condition this balance. Fires are particularly effective in causing vegetation destruction and soil exposure; moreover fires have some marked effects on physico-chemical characteristics of soil, since destroying organic matter in surface layers they alter permeability, porosity, aggregate stability and then erodibility of hillslopes. Surface runoff is also increased. Burnt areas of a small Ligurian river basin were identified over a period of 15 years, from 1982 to 1996. Recovery rate of vegetation cover and restoration of the original organic content and then of biotic control over erodibility in burnt areas were evaluated at the local scale. Decomposition tests and collection of leaves by traps to measure leaflitter production were also performed. Experimental evidence suggests that non-linear interaction between forest fire processes and extreme rainfall processes in small semiarid Mediterranean watersheds could leave to irreversible local desertification conditions.

AGRO-ENVIRONMENTAL MEASURES AND SOIL CONSERVATION: RESULTS IN SOME AGRICULTURAL ITALIAN AREAS

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The economic tools are increasing their weight in the environmental policy of the European Union. The Fifth Program of Environmental Action, close to the provisions constraints, it entrusts to the tools of market incentives and constraints the assignment of getting deeper in the productive system the external effects of the productive activities that revert on the surrounding. Beginning from the 1992 the European Union has fixed a strong push to the definition of an agro-environmental policy with the approbation of the Reg. 2078. Borne as a measure of accompaniment to the reform of the Agricultural Common Policy, this Reg. is assuming an importance that goes beyond of the function that it has been attributed among the finalities. In substance the Reg. 2078 constitutes a form of voluntary and conditioned support in base to which the producers sells some rights on the custom of the natural resources in change of a compensation for a lack of income. In Italy the application of this Reg. has suffered delays due in part to the character strongly innovating of the measures proposed in the national context and in part due to lack of co-ordination of the initiatives to national level, information generally insufficient and ineffective, under-valuation of the potentialities of the measures for the disadvantages zones where the soils are at very risk of deterioration. The research has demonstrated in fact that the success of this type of initiatives doesn't depend only from the definition of a report balanced among financial incentives destined to the farmers and imposition of technical limitations or environmental required amelioration. This is a necessary condition but not always sufficient for the diffusion of the practical eco-compatible is remarkable. Sociological factors and structural characteristics of the family-farms and organisational factors concerning the interactions among the subjects directly involved in the realisation (farmers, extension services, local board) contribute in equal measure to give effectiveness to the agro-environmental programs.

LATE HOLOCENE CLIMATE CHANGE AND HUMAN IMPACT IN THE SEMIARID EBRO BASIN RECONSTRUCTED FROM LACUSTRINE RECORDS

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The central Ebro Basin is the most northerly area of truly semi-arid climate in Europe. The long history of human occupation in the area has contributed to the transformation of the landscape. Pollen records, geomorphologic analyses, archeological surveys, and, recently, lake levels studies have been used to evaluate and identify the role of human and climatic factors. Some changes in the pollen records have been interpreted as deforestation and anthropogenic disturbance. However, other periods do not show a clear relationship between human population and landscape degradation. The discrimination of human impact versus climate needs a multidisciplinary research strategy and high resolution chronologies. The endorheic areas in the Ebro basin provide such an opportunity because these hypersaline lacustrine systems are highly sensitive to changes in the hydrological balance and catchment processes. Sediment cores from two lakes were selected and analysed using sedimentological, geochemical, stable isotope, and dating radiometric techniques.

SOIL SURFACE SEALING ON ABANDONED FIELDS IN THE SEMI-ARID MEDITERRANEAN - A PROCESS ORIENTED STUDY ON LAND DEGRADATION USING THIN SECTIONS UP TO LARGE-SCALE AERIAL PHOTOGRAPHS

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Surface crusts are a frequent phenomenon on fallow land in the semi-arid Ebro Basin and an important factor for land degradation. Soil surface sealing leads to a decrease of infiltation rates and by increased runoff to expanded sheet wash and rill erosion.
After ploughing, surface crusts developed in dependency of micro and meso relief and the amount and intensity of rainfall events. By its impact energy and by the bursting of soil particles, the impact of raindrops onto the ploughing rows results in splash effect on the soil surface. Additionally, slaking is caused when the soil surface is moistened. Thus, structural crusts are formed.
In the ploughing furrows, sedimentary crust build up from eroded material. In these crusts, a platy structure develops depending on the factors time and frequency of moisturing and drying. With the surface crust sealing off the plates against the outer air, the hollows between the plates expand to elliptical vesicles which are all but closed. The compacted soil reduces infiltration capacity.
The increased runoff on surface crusts was quantified by rainfall simulation experiments. The spatial distribution of crusts is documented by large-scale aerial photography; their structure and development were analysed with thin sections.

VEGETATION MULTITEMPORAL VARIATION USING NDVI FROM LANDSAT-TM IMAGES IN A MEDALUS-III PILOT AREA (GUADALENTÍN BASIN, SE SPAIN)

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The multitemporal evolution of the vegetation in a MEDALUS-III pilot area (Guadalentín Basin, SE Spain) was studied using Landsat-5 TM imagery from April 93 to May 94. The images were geometrically and atmospherically corrected. A further topographic correction was also applied using the non-Lambertian Minnaert reflectance model.
The study of the variations for the dominant vegetation types (Rosemarinus, stipa, disperse matorral, bare soil pine forest and almond grooves) was carried out by means of NDVI images and taking also into account an updated vegetation map (obtained from image classification) and DTM (30m resolution) derived parameters (altitude, slope and aspect).
The study shows that the influence of the altitude and aspect on NDVI changes is of major importance for the natural vegetation classes. Those changes are hardly sensitive to slope influence.

HSC1 Special hydrological symposia

03 Fire: impact on hydrology, sediment yield and ecosystems of Mediterranean lands

Convener: Moreno, J.M.
Co-Convener: Rambal, S.

HYDROLOGICAL REPONSE OF A LITTLE MEDITERRANEAN BASIN FLOWS AFTER FIRE

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Since 1967, rainfall and flow data were recorded on the little basin of Rimbaud. In 1990, a fire burnt 85% of the 150 hectare basin, provoking hydrological changes. The changes in the flows are assessed by comparing observations and the results of various models relating the flow to the rainfall, that are presumed to represent the behaviour of the basin before the fire. Flow modelling has been studied on different time periods. This shows that, during the tree years after fire, the annual flow increased by about 12 to 15 percent with respect to the rainfall, mainly during flood periods. The peak flows can, however, vary to a much greater extent due to the combined effects of greatly increased production from the basin and reduction in transit time. This different behaviours have been observed on the model parameter values obtained before and after fire. Thus, modelling can be used to appreciate hydrological change of a basin, independently of its physical interpretations.

EFFECT OF SEASONALITY ON FIRE CHARACTERISTICS AND POSTFIRE PLANT DYNAMICS IN A MEDITERRANEAN SHRUBLAND IN CENTRAL SPAIN

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Although the effects of fire on Mediterranean-type shrublands have been extensively studied, the variability through time of plant responses to fire is still poorly known. These temporal variability must be considered not only between seasons but also between years. In this work we present data of two sets of three experimental fires made, respectively, in early summer and in autumn of 1997 in a *Cistus-Erica* shrubland in Central Spain. Phenology of the dominant species was studied across the year, including an estimation of total number of seeds produced by the different species, and measurements on the ecophysiological status of the plant. Temporal patterns of seed dispersal were also recorded. Fire intensity was estimated by means of different sensors. After fire, resprout production and growth were measured in several plants previously marked. Seedling density and dynamics were also determined. Our data indicate that plant responses after fire, both for seeding and resprouting responses, were strongly influenced by fire season.

SEDIMENT PRODUCTION IN BURNED CATCHMENTS OF EASTERN SPAIN

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The objective of this study is to analyse the effect of forest fires, catchment structure and land-use distribution on sediment production. Analysis of sediment accumulation was performed in dams for flood and sediment control. A first set of 7 nearby dam catchments were selected for sampling in Millares (Júcar River watershed, E Spain). The catchments had quite similar substrate and climatic conditions and all of them were affected by a large wildfire in 1994. Dam catchment area, catchment relief, and percent of catchment area under each land use were variable among the sampled catchments. Sediments were sampled by cores and auger drills distributed along transects. The sediment layers, deposited before and after the fire, were separated according to the presence of charcoal. Catchment characteristics were obtained from topographic and geological maps, aerial photography, and the engineering projects that were elaborated for the dam construction. The selected methods for the sedimentation survey allow both identifying and quantifying of different sediment layers to be used to reconstruct sediment yield histories and the relationships between post-fire sediment yield and the characteristics of the catchment. Post-fire sedimentation was clearly larger than pre-fire sedimentation in the area.
This research is a part of the project Land Use Change Interaction with Fire in Mediterranean Landscapes (LUCIFER), funded by EC.

THE EFFECTS OF FIRE ON HYDROLOGICAL RESPONSE ON SEMIARID MEDITERRANEAN SMALL CATCHMENTS

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In order to evaluate hydrological response of burnt and unburnt areas a study is being carried out in Sierra del Picarcho (Murcia, SE Spain). This area was partially affected by a fire in summer 1994, and vegetation recovery is slow due to the scarce amount of rain. Three areas are studied, the burnt zone and two vegetated areas one of them with *Stipa tenacissima* and the other one with *Pinus halepensis* and Mediterranean shrubland.
The evaluation is determined at catchment and plot scales by monitoring three small catchments (7.5, 6.4 and 26 has.), and three pairs of experimental plots (30m.^{2}) in the different studied zones. Raingauges have been installed to determine intensity and total amount of rain. Across transects at the three monitored catchments, soil samples cores were collected to determine hydraulic conductivity and simple devices to detect runoff at hillslopes (runoff detectors) were installed.
The results confirm that runoff processes and sediment yield vary considerably between the burnt and unburnt areas, whereas in the two vegetated zones the results are quite similar. Runoff coefficients values at high rain intensities exceed of 50% at burnt sites, and less than 10% at vegetated areas. Runoff detectors showed that at burnt catchments the whole hillslope contributes to runoff and sediment yield, whereas only some points of hillslope at unburnt catchment contribute to it.

A generic process-based simulation model for fire-prone Mediterranean landscapes

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In the last decades, changes in land use with increase in fire occurrence lead to homogenize landscapes and drastically modify water and carbon fluxes in Mediterranean-type (MT) climate areas. Our aim in the UE project LUCIFER is to understand and simulate interactions of landscape change through species succession and fire occurrence. The fine-grain complex structure, the high occurrence of fires, particular traits developed by species in the early post-fire stages, and the few data available to parameterize models has led us to develop a model more focused both on Mediterranean ecosystems and landscapes. Vegetation cover change is first simulated at local scale. It is not an individual-based model but rather a process-based gap model: in one hand, species richness is simplified by classes of vital attributes of regeneration, life cycles and explicit resource use, in the other hand, individuals of each species are aggregated in 3 maturity classes. Competition between classes is simulated through shading effects of the upper layer on the 2 lower ones and partition of soil water and solar radiation available, proportional to cover and leaf area, influencing specific carbon budget. Then, the dynamics of each pixel is included in the landscape by the mean of the locally variable soil water resource, solar radiation and air temperature. Interactions between pixels will be the result of seed dispersal, water runoff and eventually disturbance -fire- spread from a pixel to its neighbors.

Spatial patterns of fuel and heat liberation during fire in a Cytisus shrubland in Sierra de Gredos, Spain

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Spatial variations in fire temperature occur within short distances, even below 1 m. Nevertheless, investigations addressing the spatial pattern of this fine scale variation are not common. Our objective was to determine, at 1x1 m scale, the spatial pattern of different variables related with the fire behavior. An experimental spring fire was ignited in an 8 yr. old stand in Pedro Bernardo (Avila, Spain). *Cytisus striatus* subsp. *eriocarpus* was the dominant species. We measured basal stem diameters to estimate the prefire fuel biomass. During the fire we used temperature-sensitive paints and containers as sensor of fire severity. After the fire, we measured the minimum diameter of burned branches and we estimated the heat released from biomass consumed. Geostatistical methods were used to establish the spatial pattern of these variables. The results show that: a) prefire biomass and heat released by the fire had a random pattern; b) containers and minimum stem diameter had a similar and definite spatial pattern; c) maximum temperature, measured by temperature sensitive paints, showed a gradient spatial pattern. Overall, fire severity spatial patterns were not predictible from prefire information.

EFFECTS OF TOPOGRAPHIC CONSTRAINTS ON REGENERATION PROCESSES AFTER FIRE

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We modeled the influence of elevation, aspect and slope on the regeneration process after fire in forested areas of Alicante, Spain. We used 11 Landsat TM images from 1984 to 1994, and a DTM, 10x10m resolution, resampled to 30x30 m, to extract the topographic information. The initial spectral heterogeneity was reduced by means the topographic variable aggregation in homogeneous categories. Later, we analyzed the spectral behavior of the NDVI and TM bands as a function of each topographic category and, a multitemporal analysis of these responses made possible to ordinate the landscape variability in different regions with different regeneration capabilities. The important role of TM5 band in the classification process showed that the variables characterized with this method were the humidity and the hydric stress of the landscape. We then applied a wetness index and a corrected NDVI to characterize these regions. The elaboration of "topographical regeneration models" involved a quantitative description of each topographic factor derived from a DTM as a function of their multitemporal spectral response. The results obtained have differentiated among areas showing different vegetation development under diverse conditions such as solar radiation (aspects), availability of soil nutrients (slopes) and humidity (elevation).

ANALYSIS OF SPECTRAL-BIOPHYSICAL RELATIONSHIPS IN GARRIGUE ECOSYSTEMS

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The objectives were to asses the radiometric sensitivity to the phenological variations of natural vegetation and to obtain relationships between spectral measurements and biological parameters. To accomplish this, reflectance measures and vegetation properties of a garrigue ecosystem were collected throughout its phenological evolution by means a truck-mounted spectroradiometer in Buñol (Valencia, Spain). The garrigue was 6-year-old, and developed over limestones. Spectral measures were recorded at three weeks interval from late April until July of 1997. Plant cover and height and dry and wet biomass of plots were collected at the beginning and the end of the experimental campaign. Preliminary results show that phenological variations were not significantly reflected in the spectral responses. Considering the variability among plots, significant relationships were found between spectral variables and plant height, biomass and canopy cover. In this sense, the temporal trend was replaced by a spatial analysis in which the different plant characteristics of the plots were achieved by the radiometric measures. From these results, radiometric analysis were more sensitive to spatial variability than short-term temporal variability in the garrigue ecosystem.

MAPPING VEGETATION REGROWTH BY REMOTE SENSING TO INTERPRETATE THE HYDROLOGICAL IMPACT OF FIRE

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Hydrological impact of fire is interpreted using a three points method. (1) Mapping by remote sensing the vegetation regrowth by using SPOT images and ground data acquired each year since fire. A specific image processing has been developed to link a remote sensing model (spectral mixture) and an ecological model (vegetation competition). Results give for each pixel, year by year, the cover rates of bare soil and vegetation strata (trees, bushes, herbaceous). (2) Determining hydrological evolution (production and transfer) at different time steps. The analysis eliminates the climatological evolution by using not burnt basins as references. (3) Comparing vegetation regrowth and hydrological evolution after fire.
Application concerns two small burnt basins of 1.5 km² (Massif des Maures, France) monitored for six years after fire. Hydrological impact of fire appears as a short impulsion (less than two or three years), variable in amplitude and duration for annual, monthly production (runoff volumes) and transfer (recession coefficients). Production seems to be linked to the total vegetation cover rate, and transfer seems more influenced by spatial position of regrowth patches within the basin. These results confirm the interest of remote sensing data for helping the knowledge of hydrological processes.

HSC1 Special hydrological symposia

04 Sources and transfer of water and sediment in Mediterranean river basins

Convener: Salá, M.
Co-Convener: Inbar, M.

EFFECT OF AGRICULTURAL PRACTICES ON RUNOFF AND EROSION IN VINEYARD FIELDS IN A MEDITERRANEAN CLIMATE

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The aim of the present study is to analyse runoff and erosion processes at the field scale, in relation to agricultural practices. This study is part of the Allegro-Roujan program, the main aim of which is to measure and model water and pollutant transfers in the Mediterranean viticultural agrosystem. The experimental site was the wine-producing catchment of Roujan, on the Hérault plain (South of France). Two major agricultural practices were identified in the catchment: "tillage", with mechanical weeding between the rows, and "no tillage", with chemical weeding over the whole vineyard field. Overland flows and total suspended solids (TSS) were measured and analysed at the outlet of a tilled and an untilled field. Soil characteristics of both fields were similar. Runoff was measured by pressure captors measuring water level in a Parshall flume. Total suspended solids were measured using water samplers. A first analysis revealed a clear difference in the behaviour of the two experimental fields, which was however apparent only for a limited time immediately after tilling. The difference is caused by the effect of tillage and progressively disappears according to the amount of rainfall fallen since tillage. A multiple regression analysis was performed to evaluate whether factors like amount of rain, intensity of rain and antecedent soil moisture, were useful in predicting runoff coefficient and total suspended solids.

PRESENT VERSUS LONG TERM SEDIMENT YIELD TO THE ADRIATIC SEA

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The Northern Apennine sediment yield to the Adriatic. based on suspended and (a few) bed load measurements, is currently rated at 0.030 km^3/a. The Alpine sediment yield to the Adriatic is 0.013 km^3/a. The total yield to the Adriatic. including the minor contribution from the Dinarides, is 0.050 km^3/a: one cubic kilometer of sediments (at zero porosity) is discharged every twenty years in the Adriatic Sea. One may wonder whether this rate recently increased due to human impact.
Past supply rates are inferred from the volume of deposits. The Pliocene volume has been corrected by adding the estimate of the underthrust sediments, while no correction has been attempted for the eroded marginal deposits. The estimates of 97,000 and 95,000 km^3 for the present Pliocene and Quaternary deposits, are therefore slightly lower than the volumes originally deposited. The corresponding net feeding rates are 0.021 (Pliocene) and 0.047 (Quaternary) km^3/a. respectively.
The relevant Quaternary increase in the feeding rate is due to the Quaternary widening of the Apenninic watershed and to its increased relief.
The striking similarity between present (0.050 km^3/a) and Quaternary (0.047 km^3/a,) supply rates suggests that:
i) the present-day impact of man as a geological agent is balanced by the relatively low erosion rates typical of mild climatic stages. such as the one we are living in; and/or that:
ii) current methods for measuring the sediment yield of rivers lead to underrated values.

TEMPORAL AND SPATIAL CONTINUITY OF HYDROLOGICAL PATHWAYS WITHIN A SEMI-ARID GULLY CATCHMENT. THE ROLE OF SOIL MOISTURE VARIABILITY.

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The spatial continuity of runoff generation over a hillslope is critical in determining the effectiveness of overland flow as an eroding agent. Since soil moisture is a function of the soils physical and hydrologic properties, the spatial pattern of soil moisture may be used to identify contrasting areas of hydrological response and hence the spatial arrangement of runoff producing areas. To ascertain the temporal and spatial continuity of hydrological pathways within a 3.68 ha gully catchment in central Spain, spatial patterns in surface soil moisture during dry and wet weather conditions have been recorded. During dry weather conditions, the spatial pattern of soil moisture was characterised by areas of relatively wet and dry soil, forming a mosaic of areas with contrasting hydrological response. Geostatistical analysis has indicated that these areas are spatially isolated and unconnected, with the effect that surface runoff from source areas within the catchment may be re-absorbed by surrounding areas which act as sinks for overland flow. Only during times of high intensity rainfall does widespread runoff and erosion occur during these conditions. In contrast during wet weather conditions, extensive saturation, exceeding a catchment wetness threshold, increased the spatial continuity in hydrological pathways. Geostatistical analysis has shown that the range in spatial correlation of soil moisture during this period was more than double that in dry conditions. Furthermore up to 50% of the gully catchments surface area may be hydrologically connected to a channel during wet conditions, resulting in the potential for widespread runoff and erosion. Management strategies may therefore aim to reduce the frequency of widespread connectivity by improving the soils physical and hydrological properties and thus raising the wetness threshold. Increasing spatial variation in the soils physical and hydrological properties by manipulating vegetation may also promote hydrological discontinuity.

CHANGES ON SEDIMENT AND DISSOLVED LOAD AFTER WILDLAND FIRE IN A MEDITERRANEAN RIVER BASIN

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On August 1994 a wildland fire occurred in the Arbúcies experimental basin. More than 750 ha of evergreen-oaks and pines were burnt. A peaky flood (2.3 $m^3 s^{-1}$ from 16 mm h^{-1} of rain) took place just after fire, while five floods occurred until the end of autumn. Total dissolved load rose in 60% after fire in comparison with pre-fire values. Increments in K and SO_4^{2-} concentrations were 700% and 250% respectively. At the end of flooding period, mean concentrations reached pre-fire levels (except for K). Suspended sediment performed higher. Results in relation to pre-fire values showed that, a) just after fire concentrations increased 2 orders of magnitude, from 22 mg l^{-1} to more than 2 g l^{-1} and b) mean increment during consecutive floods varied from 600% to 2300%. Maximum concentration was 27 g l^{-1} for a peak discharge of 12 $m^3 s^{-1}$, which represents fifteen times former concentrations. Small tributaries acted as main sediment sources, contrunting up to 16 kg ha^{-1} those with 65% burnt and 65 kg ha^{-1} those with 100%. These values are six times higher than simultaneous ones at the basin outlet. Considering that only 10% of the area was burnt, two facts accounted for rapid and acute effects of fire on river load: on one side, the proximity of burnt areas to basin outlet and, on the other, the concatenation of six floods, the largest recurring 8 years, immediate after fire.

Impact of gravel-mining and land-use changes on stream channel and coastal sediment supply Example of the Calvi Bay in Corsica (France)

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Beach erosion in the Calvi Bay, Corsica, is presented for last three decades and explained by a reduction of gravel and sand supply from the Figarella and Fiume Seccu coastal streams. Assessment of the present bedload transport during a 1 in 2 year flood and stream bed changes based on aerial photograph analysis and field measurements (cross-sections, long profiles, sediment size analysis) show that these streams deliver less and less sediments to the beach, hence explaining its erosion. Two main causes explain this reduction of sediment delivery : i) in-stream gravel-mining activities developed since the 1970's and ii) land-use changes affecting the watershed at the end of the 19th century. Gravel pits trapp sediments and modify channel geometry. An Alder forest colonised the mining site located in the Fiume Seccu channel, trapping most of the sand delivered by the watershed and inducing a major flood risk due to vegetation encroachment and increased hydraulic roughness. The pit located in the Figarella channel averages 600,000 m3 and corresponds to a channel degradation of 3 m. Channel degradation and paving are also observed a few kilometers upstream and downstream of the mining site due to progressive and regressive erosion resulting from the disruption of bedload transport and downstream winnoning, augmented because bed material is heterogeneous. Field measurements demonstrate that less than 60% of the beach sediment deficit results from mining. Beach erosion is also linked to decreased supply of bedload from the watersheds. Fluvial pattern has been simplified even in reaches which were not affected by mining. Multiple-channel beds have been replaced by a single channel; most of the beds observed on 1950's aerial photographs are vegetated in 1997. Agricultural decline at the end of the 19th c. is characterised by land-use changes, farming being replaced by spontaneous shrubby and woody patches, which to trap sediment more efficiently and reduce run-off. The resulting beach erosion, due to watershed and channel changes in coastal streams which have occurred since the end of the 19 c. is presently far from being under control . As mining pits should continue to trap sediments for several decades, decision-makers will have correct this situation by favouring natural or artificial sediment delivery if they intend to maintain tourist activity in the bay.

SEDIMENT TRANSFER DURING EXTREME FLOODS: AN EXAMPLE FROM THE ARAS TORRENT, SPAIN

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The flood which occurred on 7 August 1996 in the Aras torrent, was triggered by a heavy thunderstorm with an average rainfall intensity of 250 mm h^{-1}. This is a 18 km^2 mountainous catchment, tributary of the Gállego river in the Pyrenees. The flash-flood peak was of the order of 500 $m^{-3} s^{-1}$, an estimated thousand-year return period for the area. As a consequence, the campground located on the alluvial fan at the torrent outlet was flooded causing eighty-six people death and many injured. Two factors can be identified as main responsible for the high magnitude of this event: i) in-channel steep slopes which produced a high velocity flood-wave (6 m s^{-1}) ensuing a highly destructive flood and ii) the low permeability of the soil caused by an unusual rainy season. Almost no debris flows or landslides were triggered all over the catchment, reflecting the lack of water infiltration into the soil during the event. Contrastingly, mobilisation of sediment from streambed and footslopes was extremely high. That resulted after blocking and collapse of one bridge and the subsequent destruction of check dams. Prior bridge destruction, mean bedload rates reached 0.5 t $m^{-1} s^{-1}$. Sediment released by bridge destruction produced a high density flow (1.5 t m^{-3}) with an stream power of the order of 4 t $m^{-1} s^{-1}$. Even assuming a Newtonian-type flow, the competence of the torrent was enough to entrain rocks up to 10 m size, under shear stress of 10000 Pa. A minimum of 100,000 tonnes of sediment was exported out of the basin (aggradation on the alluvial fan reached 1 meter).

RECENT MAN-MADE CHANGES IN THE FLOW REGIME OF THE MEDITERRANEAN WATERSHEDS OF ISRAEL

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The natural regime of water and sediment discharge of Israel western drainage into the Mediterranean sea has been subjected to man-changes since the beginning of the century. Early activities consisted in drainage of swamps and pumping water from rivers and groundwater. Intensification of agriculture and growth of population caused the increase in the use of most of the spring water which fed the base flow of the coastal rivers. The western catchment rivers of Israel cover an area of about 11,000 km^2 and includes 20 major streams. Hydrological data is available for a period of 30 to 50 years and the total annual runoff is of the order of 150 million m^3 flowing mainly during floods in the winter rainy season. During the last 30 years, with the construction of dams and a large number of multipurpose water reservoirs, the water and sediment transport regime of most of the rivers has been drastically changed. The total capacity of the dams and reservoirs is about 80 million m^3, and it is assumed that more than half of the sediment production of the different watersheds which were delivered to the sea are deposited in the reservoirs.

QUANTIFYING THE EFFECT OF HISTORIC LAND USE CHANGE ON SEDIMENT YIELD IN THE RUHAMA BASIN, NW NEGEV, ISRAEL

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In the Ruhama Reservoir no spilling ever took place due to the high infiltration on the sandy loess soils throughout the 4.2 km2 basin and in the 1952 constructed reservoir. The reservoir has had a 100 % trapping efficiency. Since the 50s there has been a constant decrease of grazing lands in the north western Negev in an attempt to conserve soil: areas have undergone bank stabilisation contour plowing and other conservation measures. In a previous research it was demonstrated that river banks have been naturally stabilized and river widths have been decreased. but the quantifying of soil loss has not yet been undertaken. We have done this in a novel manner, by calculating not only the total mass of sediment deposited in the reservoir, but also by identifying event layers, dating some of them, and thereby calculating deposited volumes during selected periods. The calculations is based on two separate procedures - krigging using the program SURFER and a geometric Thiessen polygon approach; the volumes are similar. We demonstrate that sediment yield has been halved from 153 to 68 t/ km2 yr. Defining the exceedance probabilities of individual larger events during each of the periods shows that the decrease is due to a smaller frequency of occurrence of medium sized sediment-depositing events. This decrease is attributed to conservation measures. However, the daily rainfall record also raises the issue as to the extent whether this decrease in soil loss does not in part owe its existence to changes in temporal rainfall pattern.

LAND-USES AS DIFFERENT SOURCES OF SOLUTES IN MEDITERRANEAN MOUNTAIN AREAS: AN EXAMPLE FROM THE CENTRAL SPANISH PYRENEES

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In the Aisa Valley Experimental Station nine different land-uses have been reproduced in closed plots (30 square metres in size), including dense shrub cover, meadows, cereal crop, fallow land, abandoned land, shifting agriculture and burnt shrub cover. During five years information has been obtained from runoff, suspended sediment and solute concentration, allowing us to know the hydromorphological functioning of hillslopes during the so-called traditional management system and nowadays, and to discriminate the most important sources of sediments. In this paper solute concentration data during two years (1996 and 1997) are analyzed. The results show the dramatic influence of human activities: The highest losses of nutrientes are yielded by the cereal plot, to which chemical fertilizer is yearly added to make sustainable the productivity. Other high solute concentrations come from the fallow land plot, from shifting agriculture and from the burnt shrub plot (during the first year after fire). On the opposite, dense shrub cover and meadows loss few nutrients, confirming the moderate outputs of both runoff and suspended sediments. The paper concludes that in mountain areas the cultivation of hillslopes is not a recommeded strategy for soil conservation.

TRACING INVESTIGATION OF THE HYDROLOGICAL PROCESSES IN A SMALL MEDITERRANEAN FORESTED CATCHMENT DURING AN AUTUMN RECHARGE

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In the framework of the EC FOREX program (" impact of forests and silvicultural practices upon extreme flows "), 3 successive flood events have been observed and sampled during the autumn 1996, within a 54 ha forested Mediterranean basin (Mont Lozère network). Soil water was also collected as well as rainwater using a sequential sampler. Among the chemical tracers, K, Na, Cl, TOC and mainly silica underline the specificity of the hydrological mechanisms by showing the small impact of the direct rainwater contribution whereas subsurface flow is a dominant process. The use of silica as a quantitative tracer shows that the role of an " old " water component increases with time. This behaviour is in agreement with soil moisture data recorded during the same period. The physical context (soil texture, macroporosity due to the roots) largely explains the described processes but the basin hydrology is also clearly dependent on the Mediterranean rains characteristics (volume and intensity). The analysis of water for ^{18}O is now being performed. By using the isotopic tracing, it is expected to confirm the chemical investigation and to specify the transfer mechanisms.

SOIL EROSION AND REHABILITATION AFTER REFORESTATION

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Both reforestation and control woks have been the mos important strategies for land reclamation in soil eroded and degraded areas of Spain. In general, middle mountain areas have been used as agricultural and grazing land for centuries, and this is why they are occupied by abandoned fields and open shrubs, locally affected by intense erosion processes. Many of them have been reforested using different techniques and with very heterogeneous results. In this paper the hydrological and geomorphological consequences of afforestations are studied. The results obtained show that these effects mainly depend on the techniques used, on the topography and on the previous erosive state of the hillslope. The use of hollows anf furrows reduces considerably soil erosion, while the use of bulldozer terraces does not improve sediment yield.

DROP SIZE DISTRIBUTION FROM SIMULATED RAIN MEASURED WITH AN OPTICAL SPECTRO PLUVIOMETER

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Interrill erosion is largely controlled by rainfall characteristics. Several rainfall parameters (e.g. rainfall intensity, kinetic energy, momentum ...) are being used to characterise the eroding power of the rain. This study reports on the use of an Optical Spectro Pluviometer (OSP), which measures both drop size and fall velocity in real time conditions, in order to quantify erosivity of simulated rainfall. Calibration and validation of the OSP are described. Laboratory experiments using a nozzle type rainfall simulator have been conducted. Under controlled rainfall conditions the microphysics of rain (i.e. raindrop properties) has been measured using an OSP. The major advantages of such a pluviometer in erosion studies is the easiness and speed by which raindrop properties can be measured. Drop size characteristics of simulated rain (obtained by OSP) are compared with the most widely used (but time consuming) method of the filter paper technique. The drop size distribution measured by both methods are in agreement. The comparison reveals the importance of the sample size in the estimation of the drop size distribution. From this first analysis recommendations are given in order to reduce the sampling uncertainties in the measurement of the drop size distributions. Characteristics of the simulated rainfall are compared with natural rainfall characteristics.

HSC1 Special hydrological symposia

05 Catchment management in the Mediterranean for efficient water use

Convener: Estrela, T.
Co-Convener: Jamieson, D.

IMPROVING WATER RESOURCES BY MEANS OF LAND MANAGEMENT: EXPERIMENTS IN MOUNTAIN AREAS

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It is well known that water quality (solutes and suspended sediment content) is closely related with land uses. In mountain areas, particularly, this problem is very important, since they contribute very much to the discharge of main rivers, in such a way that an adequate land management of the headwaters can result in a great improvement of water quality in the whole catchment. The results obtained from experimental plots in the Aísa Valley Experimental Station (Central Spanish Pyrenees) help us to identify the best land management strategy in order to optimize both water quality and quantity: i) A dense shrub cover yields few sediments and low rates of overland flow (though contributing to increase the reserve of water in the soil); ii) cultivation of the hillslopes yields much water by surface runoff (with a high quantity of sediments); iii) meadows yields more water than shrub cover and they provide low rates of sediment concentration. Since most of the cultivated hillslopes have been abandoned, and consequently, the alternative is to allow a quick shrub colonization or to introduce meadows in order to increase water resources without dramatic consequences on water quality.

GUIDELINES FOR THE SUSTAINABLE MANAGEMENT OF GROUNDWATER FED CATCHMENTS

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Water resources in the Mediterranean are under severe stress due to rapidly increasing demands for agricultural production, pubic water supply and industry. At the same time there is growing awareness of the need to maintain ecological systems which provide many important goods and services. The Groundwater and River Resources Action Programme on a European Scale (GRAPES) is exploring the basic elements required to manage a groundwater fed catchment sustainably. These include data collation, sustainability indicators, hydrological modelling, climate change scenarios, social perception, agricultural subsides and environmental protection. This paper presents step-by-step guidelines which include these elements for planning and managing heavily utilised groundwater fed catchments throughout the Mediterranean and the rest of Europe.

Sustainable Water Use in Europe

(W. Krinner, C. Lallana, J. Rodriguez, T. Estrela)

The report presents a detailed analysis of the major factors influencing water use, considering agriculture, population growth, urbanisation, industry and tourism. The importance of the various sectors in terms of economy, employment and water abstraction is described and quantified. Also the major trends observed are analysed. The study reveals fundamental differences between countries in relation to agriculture, irrigation, tourism or industry. It shows that in many Southern European countries an important share of total water abstraction is dedicated to irrigation with figures ranging between 50% and 80% in Portugal, Greece, Spain and Italy. In contrast, in Central and Northern European countries the major part of total water abstraction is being employed for public water supply and industry. As varied as the respective economies and uses of water are the specific problems faced in the field of environment and resource management. Whereas many countries in Central and Northern Europe are mainly concerned with water quality and the ecological state of water resources, in many countries and regions of Southern Europe the predominant water issue is availability. The study points out how under certain conditions the overexploitation of water resources can lead to decreasing groundwater levels, seawater intrusion, droughts and even desertification. The problems of overexploitation of water resources are extremely complex, not only from an hydrological point of view but also regarding the socio-economic and political circumstances. Solutions have to be environmentally sound as well as social and politically feasible. The report includes a review of a variety of potential policy responses, describing the fundamental international treaties and programmes in relation to water policy as well as the potential measures of demand management and infrastructure responses. The study recommends that future research should concentrate on the improvement of the present state of information, trying to establish reliable records on a European scale and provide meaningful information to decision makers. The complexity of the problems to be tackled has to be fully pointed out and understood if programmes and regulations shall be effective, not only in scientific and technological terms but also from socio-economic and political point of view.

ANALYSIS OF THE RAINFALL VARIABILITY BASED ON THE EPA AND RADAR DATA AND THE RUNNOF EFFECT IN A CATCHMENT AREA

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Taking into account the complicated orography of the mediterranean area and the heavy rainfalls and floods recorded every year, the analysis of the orographycal influence over the rainfall in this region is very important. The objective of this contribution is to show the first results obtained from the raingauge network *EPA (Eje Pluviométrico Altitudinal Delta-Sant Llorenç)* installed recently in Catalonia, Spain, joined with the meteorological radar information. This pluviometric network is distributed along an axis that starts in the river Llobregat mouth and finish in the Sant Llorenç de Munt summit (1105 m a.s.l). It is constituted by 9 tipping-bucket automatic raingauges (rainfall overtturning 0.2 mm), some of them connected by phone. It covers an area less than 500 km^2 characterizated by a strongly mountainous orography with some slopes near 25% Although this area can be considered as a flood-prone zone, it is thickly populated and has a great number of industries. The torrential catchment of the *"Riera de las Arenas"* placed into the area covered by the EPA allows to know the flow answer to the rainfall.

AN ASSESSMENT OF LATE FLASH FLOODS EVENTS IN SPAIN

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Spain lies in an area of transition between very different meteorological zones, being affected by masses of predominant air with a wide variety of characteristics which gives rise to steep thermal and rainfall gradients. Moreover, many Spanish rivers, especially in the Mediterranean Area, are short and steeply-sloping, which makes them act as vicaries, completely dry at times and at others serving as channels during torrential rain, which give rise to catastrophic flooding. In this paper, a general approach on the flash flood problem in Spain is made. Flood characteristics are described taking into account the different meteorological phenomena and physical and territorial framework and the way of how both are influencing the prevention and forecast of floods. This description is followed by a general overview on hazard and vulnerability assessment, emphasizing the complex situation created by consolidated urban areas in flood zones. Land-use planning and criteria for planning permissions are considerated in this paper as key points, being described the legislative framework and their actual implementation. Late flash flood events in Spain as Biescas (1996) and Badajoz (1997) are presented as case studies, focusing the different

ADVANTAGES AND POSSIBILITIES FOR ALTERNATIVE CONJUNCTIVE USE AS USED IN SOME SPANISH BASINS.

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Conjunctive use schemes in arid areas, usually make use of artificial groundwater recharge from imported water, and from surface water in local ephemeral rivers. In alternative conjunctive use of groundwater and surface water more groundwater is pumped in dry years, and more surface water is derived in wet periods. Differences in aquifer storage between high levels after wet periods and low levels after dry years allows the use of variable surface water resources without need to employ groundwater recharge, which is in general more expensive and difficult to operate and implement. Assessment of gw-sw relationship is crucial for an adequate evaluation of water interchanges between them. Another important point is the artificial modification from gaining to loosing streams due to human intervention.That is usually due to an increase of pumping or of aquifer recharge. Alternative conjunctive use is adequate for basins where thewater contribution from rivers is higher than ground water safe yield. Being in general much less expensive than artificial recharge. It can be convenient for irrigation where high water prices can not be afforded. In some cases this option can be used to increase the yield of existing surface developments, or obtain environmental gains or improve the water quality of some aquifers. In complex systems efficient models able to analyse many alternatives are needed. An efficient DSS developed at the Dept of Hydraulic and Environmental Engineering of the Universidad politecnica deValencia has been applied to many complex systems in Spain.

HYDROLOGICAL CHANGES CAUSED BY EXPANSION OF ALMOND MONO-CULTURES IN THE UPLANDS OF SOUTH EAST SPAIN

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During the past decades, the diverse system of subsistence agriculture in south east Spain (annual rainfall of c. 300 mm) has been overturned in favour of large scale plantations of almond trees without consideration for topography and related spatial patterns in soil hydrological properties. The objective of this paper is to investigate the changes in soil hydrological properties brought about by this land use change on phyllites and slates and their implications for the water balance. Frequent tillage leads to denudation on the convexities resulting in thin stony soils as well as transport of stones along the slopes and kinetic sieving creating a stone mulch in the narrow valleys. Hence the water holding capacity of the topsoil is reduced by cultivation which will lead to deeper infiltration of rainfall and reduced evaporation. Modelling using the PATTERN coupled hydrology and vegetation growth model has shown that the hydrology of the thinner soils is much more dynamic: they become much more wet and much more dry than the thicker soils. The impact of stones on hydrology is complex and in part dependent on the amount of vegetation cover. These results have implications for the sustainability of agricultural cultivation on shallow soils

OCEANS & ATMOSPHERE (OA)

OA1 The thermohaline circulation

Convener: Colin de Verdiere, A.
Co-Convener: Schott, F.

COMPARATIVE ANALYSIS OF MEDITERRANEAN WATERS SPREAD AREA IN NORTHERN ATLANTIC IN VARIOUS SPATIAL AND TEMPORAL SCALES

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The fact, that the Mediterranean waters (MW) are present in a wide area of Northern Atlantic is known from early 1940-th. The analysis of MW spreading, based on modern climatic World Ocean Atlas (NODC-94) is proposed. Mean annual and seasonal fields of intermediate salinity maximum (ISM) and their depths are constructed. From these maps follow, that MW are spread from Gibraltar region not farther then 30-35 W on strait latitude. But the analysis of all available direct hydrophysical measurements (IO RAS, Obninsk WDC and NODC) shows, that the waters with presence of ISM, located at 700-1400 m, can be observed to west from Mid-Atlantic Ridge. However, in far away from a source-region, the probability of ISM detection is lower. In western part of these maps irregularity is appreciable either in detection of ISM depths, salinity values on this depths, and their space discretization. Last is apparently connected to discrete mechanisms of MW transport - partially by IE lenses. The area of significant influence of MW on the ocean heat and salt content by using mean T,S fields can be contoured; and it is preferable for climatic evaluations and numerical accounts. But the other mentioned above facts need be considered. This work is supported by RBRF grant N 96-05-65287.

OBSERVATIONS OF THE MEDITERRANEAN UNDERCURRENT ALONG THE CONTINENTAL SLOPE OFF PORTUGAL

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An analysis is presented of velocity and temperature data obtained between June and November 1997 with Aanderaa current meter moorings on the Portuguese continental slope along the main route of the Mediterranean Undercurrent, in the frame of the European Union MAST-III CANIGO Project. The moorings, in pairs (at the upper and at the mid-slope), were respectively near 8° 45'W off Algarve, and at about 37° 30'N and 38° 30'N off the western coast of Portugal. The current meters were located at three levels, corresponding to the Central Water (~300 m) and to the Mediterranean upper core (~800 m) and lower core (~1200 m); the moorings off south Portugal had an extra current meter underneath the Mediterranean Undercurrent (~1800 m). Some common features were found at these three sites: (i) the mooring on the upper slope showed the Mediterranean Undercurrent well aligned with the local isobaths as being controlled by the ambient vorticity; (ii) the mooring on the upper slope presented higher speeds at the levels of the Mediterranean Undercurrent than the mid-slope mooring; (iii) the velocities reached by the upper core were usually higher than those reached by the lower core. There was a general downstream deceleration of the Mediterranean Undercurrent, with velocities reaching peak values at 800 m of about 50 cm s^{-1} off Algarve, about 40 cm s^{-1} at 37° 30'N, and about 30 cm s^{-1} at 38° 30'N.

THE THERMOHALINE CIRCULATION IN THE SOUTH ATLANTIC: ESTIMATING THE CONTRIBUTION OF THE MAJOR WATER MASSES

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The South Atlantic Ocean has a peculiar contribution to the meridional thermohaline circulation (MTC); the transport of heat is directed towards the equator where the ocean gains heat from the surface. The contribution of the major water masses to the MTC in the South Atlantic is investigated with the results of model simulations. The model is an eddy-resolving (1/3°), sigma coordinate primitive equation model (SPEM), forced with a complete and consistent surface forcing including winds, heat and freshwater fluxes from the ECMWF re-analysis and a sea-ice model. The model domain covers the South Atlantic from 16°S to 76°S, and thus includes the Weddell Sea, and communicates with the other oceans through open boundaries. A 30 year long simulation is analysed in terms of water mass properties. Dominant water masses are identified, and their circulation and respective contribution to the MTC are investigated. A particular attention is given to the topographic control of the circulation of deep waters. A global circulation scheme is derived and is confronted to the interpretation of the WOCE hydrographic sections carried out in this basin.

CHANGES OF DEEP CIRCULATION IN THE WESTERN EQUATORIAL ATLANTIC INFERRED FROM TRACER AND CURRENT MEASUREMENTS (1993-1996)

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Hydrographic data and tracer (oxygen, CFC, nutrients) analyses have been performed together with L-ADCP current measurements in the area located between the 7°30N parallel, the 35°W meridian, and the american continent during March 1993 (CITHER 1 cruise), September 1995 and May 1996 (ETAMBOT 1 and 2 cruises). Water masses and deep flows are studied using vertical and isopycnal distributions on the levels of the Upper North Atlantic Deep Water, Lower North Atlantic Deep Water and Antarctic Bottom Water. Circulation patterns and isopycnal distributions of the different parameters are compared for each cruise in order to characterize the processes implied in the variability of water masses and transports inside the Deep Western Boundary Current. The changes of the depth of the CFC cores and their CFC and salinity contents emphasizes the interest of transient tracers to follow the circulation variability on regional and global scales.

INTERANNUAL THERMOHALINE CHANGES AT THE EASTERN MARGIN OF THE NORTH ATLANTIC SUBPOLAR GYRE 1991 - 1996

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Five hydrographic repeats of WOCE section A1E (Greenland - Ireland) between 1991 and 1996 reveal strong interannual changes of watermass characteristics at the eastern margin of the North Atlantic subpolar gyre. Between 1995 and 1996 a pronounced temperature and salinity increase was observed in the Subpolar Mode Water (SPMW) of the Iceland Basin due to a westward shift of the Subarctic Front. The characteristics of the anomaly were similar to an anomaly that was advected from the subtropical gyre into the eastern subpolar gyre in the 1950s. Along the whole section the density decreased in the upper 1000 m between 1995 and 1996, which was accompanied by an increase of the heat and salt content of the SPMW layer and by a positive anomaly of the sea surface height as inferred from Topex/Poseidon altimetry. The thermohaline changes were connected with a strong decrease of the intensity of the Westerlies due to the North Atlantic Oscillation, which reduced the eastward spreading of cold and less saline waters from the western subpolar gyre. Below the SPMW, a cooling and densification of the Labrador Sea Water (LSW) was observed in the period 1991 to 1996 due to the eastward spreading of newly formed LSW.

TRANSIENT TRACER OBSERVATIONS IN THE NORTH ATLANTIC

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Distributions and variability of Chlorofluorocarbons (CFCs), tritium, helium-3, and carbon-14 obtained during several occupations of the WOCE legs A1 and A2 in the North Atlantic are presented and discussed. From the transient input of these tracers and the enrichment of helium-3 in subsurface waters ventilation ages of water masses may be assessed. Convective renewal from the surface contributes to the overflow waters at the Greenland-Iceland-Scotland-Ridge (DSOW, ISOW) and to LSW in the Labrador Sea. We investigate the pathways of water masses and, relating the tracer data to the signals observed in the overflow areas and in the Labrador Sea, to estimate mean transfer velocities. For part of the data in the eastern North Atlantic an optimised multi-parameter approach (OMP) we determine the influence of mixing of the tracer-free Eastern Basin Bottom Water. The CFC- and the tritium/helium-3 ages for the remaining younger water are calculated from the corrected tracer values. The differences between corrected and uncorrected ages are significant and are due to a fraction of the water which is much older and therefore essentially tracer-free. The amount of this old water could be estimated from the tritium data.

THE 1996 SEA SURFACE HEIGHT ANOMALY OF THE NORTH ATLANTIC SUBPOLAR GYRE

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A time series of more than four years of the Corrected Sea Surface Heights (CORSSH) from the TOPEX/POSEIDON (T/P) altimeter mission as provided by AVISO, was taken to investigate sea level height anomalies in the North Atlantic. The period from 1992-1996 was used to perform a long term Mean Sea Level (MSL). Comparing this MSL with annual and seasonal mean fields a sea surface height anomaly could be clearly identified for the year 1996. This anomaly becomes in particular visible, when periodic variations of the sea surface (due to seasonal changes in the surface temperature and surface moisture flux) are identified and removed. The sea surface height anomaly coincides with a drastic decrease of the NAO in 1996. In order to investigate possible correlations between sea surface height and the Sea Surface Temperature (SST) and to show the impact of the inverted barometer correction to the CORSSH, complementary data sets were analyzed by similar methods. In particular the variations in SST data (taken from AVHRR) and SLP data (from NCAR/NCEP) were used to look also for 1996 anomalies.

SEASONAL VARIABILITY OF DEEP CURRENTS IN THE EQUATORIAL ATLANTIC: RESULTS FROM THE DYNAMO PROJECT

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Comparison of the three different numerical models investigated in the European DYNAMO project - models based on geopotential levels, terrain-following (sigma) coordinates, and isopycnic layers - reveals strong similarities in the pattern of seasonal current anomalies in the equatorial Atlantic: these include basin-wide bands of zonal currents alternating in eastward and westward direction, and a variation of the Deep Western Boundary Current that, depending on latitude, manifests itself either as a pulsation of transport or an offshore meandering of the current core. The model analysis, supported by further sensitivity experiments, identifies the dynamical cause of the variability, and may contribute to an interpretation of observed time series of DWBC transport. The model study further helps to elucidate the relation between (observed) deep transport variations near the western boundary and variations of integral quantities such as the net meridional transports of mass and heat in the tropical Atlantic.

STRUCTURE AND VARIABILITY OF MERIDIONAL OVERTURNING IN THE ATLANTIC OCEAN: MODEL PERSPECTIVES

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Large-scale models of the Atlantic's thermohaline circulation, while often successfully being tuned to reproduce the (maximum) mass or heat transport, continue to differ quite strongly with respect to the threedimensional structure of the circulation, with potential impact on their response to changing atmospheric forcing. In recent years, a host of sensitivity studies and intercomparison exercises with medium- to high-resolution models has begun to unravel the factors (physical and numerical) that appear to control the overturning circulation in numerical solutions. The first part of this talk will be devoted to a review of relevant model results, especially highlighting the fundamental role of mixing processes in northern outflow regimes. The second part will be concerned with different mechanisms that lead to a variability of the deep overturning cell on seasonal to decadal time scales, and may cause the variability of the DWBC observed in the tropical Atlantic.

THE GULF STREAM - DEEP WESTERN BOUNDARY CURRENT CROSS-OVER: RESULTS FROM FLOAT OBSERVATIONS

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Two major branches of the meridional overturning circulation cross off the east coast of the US at about 35N: the equatorward-flowing Deep Western Boundary Current (DWBC) and the poleward-flowing Gulf Stream. In 1994-1995, 26 RAFOS floats were launched in the DWBC north of the cross-over region, 14 at 3000 dbars and 12 at about 850 dbars.
About half of the 3000-dbar floats left the boundary at the cross-over and show evidence of an interior pathway for some fluid in the DWBC. The other half of the deep floats crossed under the Gulf Stream near the boundary, of which three continued equatorward in the DWBC, one traveling a total distance of about 6400 km (from 43N to 20N) with an average speed of about 10 cm/s.
The deep floats also clearly reveal that the DWBC is deflected downslope as it crosses under the Gulf Stream in order to conserve potential vorticity. The floats generally followed the isobaths until they reached the cross-over region, at which point temperature increased and the trajectories deviated toward deeper water. The total increase in water depth along the float tracks was similar to the change in depth of the thermocline across the Gulf Stream, about 800 m.

TRACER STUDIES IN THE SUBTROPICAL GYRE OF THE SOUTH ATLANTIC

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Tritium and CFC data are used to study the upper circulation in the South Atlantic. The data originate from the WOCE, SAVE, and AJAX programmes and are merged into a single quasi synoptic data set containing transient tracer information over the last 15 years. The data show tritium enriched water leaking from the Indian Ocean into the South Atlantic whereas the tritium input from the Pacific Ocean via the Drake Passage is low. The data also show accumulation of tritium in the subtropical region of the South Atlantic, indicating recirculation processes within the Subtropical Gyre. Ventilation rates for thermocline water are inferred from imbalances in the tritium budget. Analysis of CFC/tritium ratios provides a new and powerful tool for water mass dating in the upper waters. Application of this method yields turnover times within the Subtropical Gyre in the range of 10 to 20 years.

THE MEDITERRANEAN OUTFLOW AS DESCRIBED BY THE OCCAM GLOBAL OCEAN MODEL

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The OCCAM global ocean model is a 1/4x1/4° resolution Ocean General Circulation model (OGCM) of the entire World's oceans with 36 levels in the vertical. The model includes the Mediterranean Sea and the Straits of Gibraltar are open (albeit a little wider than reality). Even at this resolution some of the processes which determine the properties of the water spreading into the North Atlantic are not fully resolved. The OCCAM model maintains a realistic volume flux of high salinity water out of the Mediterranean but it is likely that this water is "over-mixed" and simulations over longer time periods would result in a water mass less dense than that observed in reality. This poster details the processes as described by the model and compares these with current perceptions based on field measurements.
Methods of improving model representation of outflow dynamics and deepwater formation are being investigated as part of the CANIGO MAST III project. Early results from these approaches are also presented, these include:
1. Coupling a stream-tube model where the stream-tube model uses topographic information at finer resolutions than the OGCM grid and models a plume descending through ambient fields set by the OGCM.
2. Using a 2-dimensional bottom-boundary layer model to better represent the turbulent processes occurring within the bottom grid cells.

Global flux estimates and other results from the OCCAM global ocean model

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The OCCAM global ocean model has been run in the UK by a consortium of researchers from Universities and Institutes. The model is based on the standard Bryan and Cox level model but it has a free surface and include many additional improvements to the model physics. It covers the globe, including marginal seas like the Mediterranean, with a horizontal resolution of 0.25 degrees. The Arctic is handled by using a rotated grid for the North Atlantic and Arctiv oceans. The model has 36 layers in the vertical with a thickness of 20 m near the surface increasing to 250 m at depth. The poster will present will present results on the large scale flux of heat and fresh water in the model including the contribution from the thermohaline circulation. The total meridional heat flux has an almost symmetric form with heat being advected away from the equator in both hemispheres. However in the Atlantic Sector, where the thermohaline term dominates, the heat transport is northwards at all latitudes. This is balanced by a greater southward flux in the Pacific and Indian oceans. The large scale meridional transport of fresh water reflects the global distribution of precipitation and evaporation. A detailed comparison in the Pacific sector shows good agreement with observations. The model also shows seasonally varying transports through the Bering Strait, with a mean value of 0.8 Sv, and in the Indonesian Throughflow region, with a mean of 12 Sv. The Drake Passage transport has a mean of 150 Sv and shows irregular fluctuations with an amplitude of about 5 Sv.

CIRCULATION PATTERNS IN THE CAPE GHIR FILAMENT AREA DURING OCTOBER 1997

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On September 1997 did an oceanographic cruise, Filament 97, on board of the R/V HespThetarides between Cartagena (Spain) and Canary Islands. Our objective is to determine the Canary Current pattern on the slope and the Northwest African continental platform between Gibraltar and Cabo Ghir, its recirculation along the Northwest Africa slope associated to the baroclinical coastal jet, and its return to the interior ocean in the Cabo Ghir filament region. We made six sections and we collected XBT (Expendable Batithermograph), ADCP (Acustic Doppler Current Profile), CTD (Conductivity Temperature Depth) and thermosalinometer data, and we launched two ARGOS buoys. In this work, we present the vertical distributions of temperature, salinity and density, as well as some circulation patterns inferred form the ADCP and driffeter data. During the Cruise the winds were weak coinciding with an upwelling relaxation period. This produced a weakening in the upwelling vertical circulation cell and allowed us to appreciate the importance of the horizontal circulation cell which links the Canary Current and the coastal current system.

MULTI TRACER ANALYSIS

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The tracer data of the cruise Meteor 18 (WOCE A1) belonging to the deep (>1000 m) eastern North Atlantic is analyzed. This analysis faces problems connected with two kinds of mixing. One is mixing of different water masses the other mixing of parts of the same water mass with different ages (interior mixing). The first kind of mixing is calculated by an Optimum Multiparameter Analysis. The results of this analysis are used to remove the influence of the tracer free Eastern Basin Bottom Water. The freon concentration age and the tritium helium age for the remaining water are calculated from the corrected tracer values. The differences between the two ages are still bigger than the errors of the ages. This is due to a part of the water which is essentially tracer free. It is estimated from the tritium data. If the influence of this part is removed as well the ages are in agreement within the errors for many measurements. There is no hint that the remaining differences result from mixing of different water masses, but they are distributed as it is expected for interior mixing.

ATOM: MODEL CONCEPT AND FIRST RESULTS

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The AWI Tracer Ocean Model (ATOM) is a global model intended for investigating the oceanic carbon cycle and its variability. The ocean model has 2 x 2 deg. horizontal resolution and 99 vertical levels. It consists of two MOM2 type submodells with the one for the North Atlantic formulated on a rotated grid with the pole on the geographic equator. The biogeochemical model is based on HAMOCC. Only the combination of a prognostic ocean and an advanced carbon cycle model allows to simulate the reaction of physical and biological carbon pumps to changes in the atmospheric forcing.

First experiments with the model address the large scale oceanic circulation. The uptake and transport of CFCs are simulated over 50 years and the resulting distributions are used to assess the ability of the model to reproduce large scale advection and convective mixing. The sensitivity of the model with respect to different subgrid scale parameterizations will be discussed. A major concern for any large scale model is the transfer of dense water across topographic obstacles, especially the Greenland - Scotland - Ridge. The effect of different bottom boundary layer submodels on the overflow and the THC in the model will be analysed.

BENGUELA CURRENT EXPERIMENT

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In order to study the northward flow of intermediate water in the Benguela Current and its extension, a program was put together between scientists of WHOI, NOAA/AOML and Sea Fisheries (South Africa). This program is a component of KAPEX (Cape of Good Hope Experiment) a joint US, Germany, and South Africa effort. The main objective of the program is to obtain the first subsurface float measurements of the northward flow of intermediate water in the eastern South Atlantic and to measure the characteristics of this water. During September 1997 a cruise took place aboard the R/V *Seward Johnson*, from Cape Town to Recife. The main objectives of this cruise were: to launch an array of 32 RAFOS floats and 10 surface drifters; to perform an intensive survey to determine the characteristics of the flow; and to search for and study Agulhas rings which carry Indian Ocean waters into the Atlantic. Hydrographic casts (CTD-O2) and direct measurements of currents (ADCP/LADCP) were performed along 30°S (between 14°E and 7°W) and along 7°W (between 33°S and 18°S) to study the characteristics and paths of the intermediate water flow at the time of deployments. Three anticyclonic Agulhas rings were identified through intensive XBT surveys guided by satellite images of sea surface height. This poster is an overview of the experiment and the preliminary results.

THE ATLANTIC CIRCULATION: A SENSITIVITY STUDY USING DIFFERENT FRESHWATER FLUXES

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To investigate the glacial ocean circulation a coupled ocean / energy balance model (EBM) is forced by different freshwater fluxes. They only differ in the North Atlantic region and only by less than 0.1 Sv. Nevertheless, two completely different circulation regimes go along with these forcing fields. The first regime is marked by weak North Atlantic Deep Water (NADW) production and a strong presence of Antarctic Bottom Water (AABW). This pattern agrees with results derived from deep sea sediment data. The second regime is characterised by unrealistically high NADW production and absence of AABW. We found, that the resulting circulation pattern is only dependent on the surface fresh water flux but independent on initial conditions. Multiple equilibria were not found. It is argued, that hysteresis with respect to freshwater flux changes found in other models could be an artefact of the procedure.

In a series of experiments we find a critical value for the fresh water input into the high latitude North Atlantic. This value corresponds to glacial conditions, while recent conditions provide for a relatively strong, stable THC.

FORMATION OF NORTH ATLANTIC DEEP WATER IN THE SUBPOLAR GYRE – A MODEL INTERCOMPARISON STUDY

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The outflow of dense water masses from the Nordic Seas into the subpolar North Atlantic plays a crucial role for the thermohaline circulation of the World Ocean. Whereas in the past, the overflow processes entered GCMs as subgrid-scale processes and were thus depending on the numerical formulation of the physical system and the parametrization schemes, the models in the European DYNAMO project explicitely resolve the topographically controlled transport of dense water masses.
The models follow different concepts for the discretization of the vertical coordinate. Results from the intercomparison of a level model (GFDL-MOM), an isopycnic model (MICOM), and a sigma-coordinate model (SPEM) will be presented with focus on the performance of the models in critical regions like the Denmark Strait and the Iceland-Faroes-Shetland ridge system, and the net effect of deep convection in the Labrador Sea on meridional overturning.

INTERMITTENT CONVECTION AND ITS CONSEQUENCES ON THE THERMOHALINE CIRCULATION IN GCM'S

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Intermittent convection and its consequences on the stability of the thermohaline circulation are investigated with a global circulation model (GCM) and simple box models. A two-box model shows that intermittency is a consequence of the non-linearity of the equation of state and of the ratio of heat and freshwater fluxes at surface versus the fluxes at depth. We classify convection into three classes according to the vertical gradient of temperature and salinity for unstable stratifications: (i) temperature driven, (ii) salinity driven and (iii) the combination of both. Although intermittency is possible for classes (i) and (ii) it has only been observed for class (i) in our GCM experiments. Because intermittent convection causes temporal variations of the ocean-atmosphere fluxes, a GCM cannot reach an exact equilibrium. After the switch to mixed boundary conditions intermittent convection becomes either continuous or is stopped depending on the method used for calculating the freshwater fluxes. Advective and diffusive fluxes between these regions and their surroundings change in order to balance the altered convective fluxes and therefore provide a mechanism for far field effects. A comparison between the GCM and a six-box model illustrates that this may lead to an important alteration of adjacent deep convection and of the related deep water formation.

DIRECT MEASUREMENT OF THE DEEP CIRCULATION WITHIN THE BRAZIL BASIN

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In support of the WOCE Deep Basin Experiment a large number of neutrally buoyant floats have been released within the Brazil Basin during the 1990s in an attempt to directly measure the circulation in the deep ocean interior. Three levels corresponding to the three major subthermocline water masses were selected and results from the deeper two (North Atlantic Deep Water, NADW and Antarctic Bottom Water, AABW) are described, as these were the two levels for which we were responsible. It appears that the flow in the deep Brazil Basin is unlike previous conjectures in which the circulation patterns can be characterized as being primarily meridional, both along the western boundary and in the interior. Although the existence of deep western boundary currents is quite clear in the float data, especially at the NADW level, the interior flow is dominantly zonal with unexpectedly small meridional space scales. Decorrelation times are long, of order 20–30 days and eddy kinetic energy levels are low, of order 1 cm^2/sec^2. In spite of the low energy levels a surprising number of our floats became caught up in vortices, we believe of the submesoscale coherent variety. A line of seamounts extending offshore near 20S, known as the Vitoria-Trinidade Seamounts interrupts the DWBCs and is the location for a eddy formation and apparent flow away from the boundary into the interior. Although it has been speculated that this could feed a narrow zonal current of NADW (the "Namib Col Current") our float trajectories suggest a return to the western boundary, rather than a continuation to the east.

INTERNAL DECADAL MODES OF THE THERMOHALINE CIRCULATION: ROBUSTNESS TO HIGH RESOLUTION, REALISTIC FORCING AND TOPOGRAPHY

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The thermohaline circulation shows internal modes of variability on (inter)decadal time scales in flat-bottomed ocean models forced by (quasi)constant surface buoyancy fluxes. The excitation of the variability has been explained in terms of longwave baroclinic instability in the region of separation of the western boundary current, although the period is not clearly understood yet. The oscillations period and amplitude have been shown to be sensitive to horizontal and vertical mixing. However, in such coarse-resolution models, the growth rate of baroclinic instability is controlled by viscosity and all mixing processes are crudely represented by uniform diffusivity coefficients. We therefore investigate the robustness of this variability in eddy-resolving simulations. These oscillations appear spontaneously under fixed surface fluxes but not under (too strong) restoring boundary conditions. Through the coupling to simplified atmospheric models (Energy Balanced Models, 2D zonally averaged), we analyze which atmospheric feedbacks are likely to damp or enhance the variability. Finally, we investigate the damping role of realistic bottom topography in this variability and compare the model's behavior to the observations in the North-Atlantic.

OCEAN MODELLING BY METHOD OF GENERAL ADJUSTMENT (OMMEGA)

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A lack of data results in some difficulties in the ocean climate modelling using historical data. The conventional methods of solving this problem are the use of the procedures of objective analysis and data smoothing applied to the entire basin of the ocean to restore the hydrographic fields in the regions, where the data were not statistically reliable or complete lack of data. This procedures lead to a significant deformation of the hydrographic fields, especially in the frontal zones. Unlike this formal statistical approach we have contrived the method of hydrophysical fields reconstruction called "Ocean Modelling by MEthod of General Adjustment (OMMEGA)". In this method a series of diagnostic-adjustment calculation is performed to correct the data in "poor" grid points insufficiently supplied or not supplied by observations under the influence of "good" points with reliable data. In these "good" points the T, S fields are periodically replaced to their initial values to avoid filtering under the influence of surrounding incorrect data or model deficiencies. OMMEGA allows us to restore the hydrographic fields in the areas with unsufficient amount of data, and keep the data in the initial form for the regions where the observation were statistically reliable.

DECADAL AND INTERDECADAL VARIABILITY SIMULATED WITH A REGIONAL MODEL

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We analyze the North Atlantic oceanic variability simulated with a regional version of an isopycnal ocean forced with observations. The model consists in 10 isopycnal layers that simulated the deep ocean, topped by a mixed layer and coupled with a sea ice model. The domain cover $19°N$ to $65°S$, and $98°W$ to $17°E$, the grid resolution is 1.16° zonally and 0.52° meridionally. The surface heat and momentun fluxes used to force the model were derived from the NCEP analysis. Special attention is paid to the mechanisms of generation and propagation of the surface anomalies and the role played by the subsurface water masses is studied. Sofisticated statical tools were used for this study.

ATMOSPHERICALLY-FORCED EXCHANGE THROUGH THE STRAIT OF BAB EL MANDEB

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Exchange between the Red Sea and the Gulf of Aden on synoptic time scales (days-weeks) is investigated using moored time series data collected in the strait of Bab el Mandeb from June 1995 to November 1996. Transport variations through the strait on these time scales can reach amplitudes of up to 0.6 Sv and appear to be driven by both large-scale barometric pressure variations over the Red Sea and direct wind stress variability over the strait. The transport response through the strait is strongly dependent on the forcing frequency in both cases. At low frequencies, sea level responds isostatically to barometric pressure variations over the Red Sea, forcing a barotropic inflow (outflow) through the strait during falling (rising) atmospheric pressure. However, at frequencies higher than the Helmholtz resonance frequency of the Red Sea, which occurs at a period of about 5 days, the response reverses to one in which inflow through the strait occurs during rising atmospheric pressure. The response to variations in alongstrait wind forcing also changes from a direct, nearly in-phase response through the water column for frequencies higher than the Helmholtz frequency, to a nearly out-of-phase response in shallow and deep layers at low frequencies. The reversal of the deep flow in the strait is caused by the development of an adverse alongstrait pressure gradient built up by the wind stress. The basic features of both of these forced responses can be reproduced by simple linear (fritional) models. Combined, the barometric pressure and alongstrait wind forcing appear to account for about 60% of the transport variance within the strait.

THE FORMATION OF THE INDIAN EQUATORIAL WATER

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The thermocline of the equatorial Indian Ocean is dominated by a water mass of nearly constant salinity (about 35.0) in the temperature range from 6 to 20° C, known as the Indian Equatorial Water (IEW). Outside the equatorial belt Indian Central Water (ICW) is found, which is characterised by decreasing salinities with depth. We hypothesise that IEW is not a distinct water mass, but instead is formed by enhanced vertical mixing of ICW near the equator. Unique to the equator are vertical alternating currents, the equatorial Deep Jets, and high vertical wave number (0.005 cpm < k <0.01cpm) internal waves. Using hydrographic data and current profiles from the WOCE section IR4 as well as moored ADCP and current meter data (WOCE-Array ICM-8), vertical mixing in and below the thermocline is investigated. Vertical diffusivity estimates yield $K_z > 1 \times 10^{-4}$ $m^2 s^{-1}$ within half a degree of the equator. The physical processes leading to enhanced mixing are Kelvin-Helmholtz instabilities as well as critical layer absorption of the high wave number waves in the sheer zones of the deep jets. A simple advection-diffusion model is integrated to show the transformation of ICW into IEW by enhanced vertical mixing. The role of other transformation processes are discussed and quantified.

The response of the thermohaline circulation in the Hadley Centre coupled model to increasing levels of atmospheric CO_2.

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The time dependent response of the thermohaline circulation (THC) in the north Atlantic to increasing levels of atmospheric CO_2 has been studied using the Hadley Centre coupled ocean-atmosphere model HADCM2.

For a gradual increase of CO_2 to double its initial value, the THC in HADCM2 reduces by about 20%, compared with a typical reduction of about 30% seen in other models. In scenarios where CO_2 is gradually increased and then held fixed at a higher level, the THC in HADCM2 recovers quickly once the level of CO_2 is fixed, and in one case goes on to increase to 25% above the level in the control integration. In a previous similar study, the THC continued to weaken for some time after the CO_2 level was fixed, before making a slow recovery. The swift recovery of the THC in HADCM2 is due to the advection of positive salinity anomalies into the sinking region of the north Atlantic.

This study confirms that some reduction in THC is likely as CO_2 increases, due to greater increases in precipitation than evaporation at high latitudes. At longer timescales the changes in THC are uncertain and depend on the balance between competing feedbacks.

SIMULATION OF THE VARIABILITY OF THE MERIDIONAL OVERTURNING CELL IN THE NORTH ATLANTIC OCEAN USING A SIGMA COORDINATE MODEL

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The meridional overturning stream function (MOS) and the meridional heat transport (MHT) are variables commonly used to characterise the strength of the thermohaline circulation, especially in the North Atlantic which is the region where the most ocean deep water is formed. A topography following coordinate model (σ-coordinate model, SPEM) is used to simulate and understand the variability of the MOS and MHT. The model domain covers the North Atlantic and extends approximately from 20°S to 70°N, with a resolution of 1.2°. The model is forced with the 15 year monthly mean climatology of air-sea fluxes derived from ECMWF reanalysis, and has the particularity to explicitly resolve the overflow of deep waters across the northern ridges. The processes responsible for the variability of the MOS and MHT will be discussed and the contribution of the σ-coordinate to the overflows and the formation of the Deep Western Boundary Current will be underlined. The comparison with results of vertical geopotential level models and isopycnal vertical coordinate models will also be presented.

ABOUT THE SEASONALITY OF THE LSW ARRIVAL WEST OF THE MID-ATLANTIC-RIDGE AT 47° N

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Several years of data from moorings west of the Mid-Atlantic-Ridge on the 48°N section WHP-A2 reveal that the newly formed Labrador Sea Water LSW arrives only in early spring of each year. Temperatures and salinities during these periods show little variations, indicating a rather homogeneous water mass. The changes from periods dominated by the LSW to those dominated by waters from the subtropical gyre are abrupt and occur within a week. For the rest of the year the warm and salty waters from the south show strong variations in temperature and salinity of 20 -30 days periods. The vertical temperature profiles at the mooring sites are dominated by long warming and short cooling phases. Additional data from C-PALACE floats in the vicinity of the moorings provide valuable information on the development of temperature and salinity for the top 1500 m layer, particularly in winter.

DECADAL CHANGES IN THE THERMOHALINE CIRCULATION OF THE NORTH ATLANTIC

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The spatial and temporal temperature and salinity changes of repeated transatlantic hydrographic sections at 48, 36 and 24,5° N since 1957 are used to describe significant changes of the intermediate and deep waters. They are closely related to changes of LSW core properties. Differences in warming and cooling trends in the subpolar and subtropical gyres are explained by different spreading times of the LSW. We suggest a rapid spreading of the LSW signal through the whole North Atlantic: from 1 year to the Newfoundland Basin to 22-25 years to the deep western basin at 24,5 N, the cooling signal propagates even faster. Water mass and heat transports suggest an intensification of the MOC in 1981 compared to 1959 or 1993. An intensification of both MHT and MOC in 1981 coincided with the sharp decrease of both LSW production rates and total zonal mean transports at 36 N. The role of the recirculation during this period was reduced. Two scenarios of the interaction of the MOC within the circulation of the North Atlantic are proposed, suggesting that LSW is not a main component of MOC but the main role belongs to the deeper (DSOW) transport.

CONVECTIVE CIRCULATION IN MESOSCALE ABYSSAL BASINS

Stommel and Arons in their famous work gave an explanation of deep circulation in the ocean on a rotating sphere. Their theory neglects surface wind stress effects to the first approximation and focuses on buoyancy driven flows responsible for the formation of stratification of an oceanic basin. The theory of Stommel and Arons also has led to thermocline theory which has been studied intensively last decades. The comparable theory of a pycnocline and a buoyantly driven circulation in mesoscale basins with a size ranging from 50-1000 km does not exist. The small size of a basin over-rides the planetary beta-effect producing another first order dynamical balance. This study presents a candidate theory of buoyancy driven circulation in mesoscale basins. Numerical simulations together with laboratory modeling are used to show the main features of the buoyancy driven flows. Two types of experiments are discussed. The first one is with heating through the top and cooling through the outer wall. The second one is with both heating and cooling through the side wall. Such types of boundary conditions are typical for lake and semi-enclosed seas. Mesoscale circulation in deep oceanic hollow sand trenches also may have a similar origin. Azimuthal circulation definitely has a layered structure in the vertical direction. The number of layers of cyclonic and anti-cyclonic flow depends on the distribution of the heating and cooling along the boundary of the basin and from the type of dynamic boundary conditions on the surface of the basin. However at least one cyclonic flow and one anti-cyclonic flow exist for all boundary conditions. The circulation in the vertical plane consists of one cell or two cells of different sign depending on where the heating is applied. Heating of the outer wall induces upwelling but cooling induces downwelling within the very thin sidewall boundary layer. In any case likely to be found in the ocean upwelling occupies the interior of the deep basin supporting the thermocline. The closeness of our measured and calculated temperature profiles to horizontally uniform stratification suggests also an energy argument that produces a non-linear velocity scale.

PATHWAYS OF INTERHEMISPHERIC EXCHANGE IN THE EQUATORIAL ATLANTIC: LAGRANGIAN ANALYSIS OF HIGH RESOLUTION MODELS

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The simulation of drifter trajectories in ocean circulation models represents a powerful tool for following pathways of water masses in four dimensions, an alternative to Eulerian diagnosises, particularly in flow regimes with strong temporal variations. In the present study, we will focus on the low latitudes of two high-resolution models of the North Atlantic (CME, DYNAMO), which were run recently at IfM in Kiel, to elucidate the pathways of (a) water masses of South Atlantic origin into the Caribbean Sea, (b) southward, interhemispheric transport of NADW and its interaction with the equatorial current variability. A time- and spatial-sensitive trajectory algorithm is introduced to compare these two models with respect to the dynamic of the equatorial - predominantly zonal - flow system and the role of retroflection eddies, shed off Brazil.
Further studies of interhemispheric transport mechanisms build on an open-boundary, eddy resolving submodel of the equatorial Atlantic that is being developed in the frame of a new family of models for the Atlantic Ocean (FLAME).

SEASONAL VARIABILITY OF THE WORLD OCEAN CLIMATE

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A dynamically balanced circulation of the World Ocean has been obtained using the adjustment of Bryan-Cox type model to Levitus (1994) climatology and Hellermann (1983) wind stress. The adjustment has been performed via integration of the equations on 1 degree grid until variability with time scales faster than 10 days has been removed. At low latitudes the residual variability time scale was found to be 250 days. The computations were performed separately for the annual mean and four seasonal climatologies. Annual mean transports in through the major choke points are: 20 Sv Florida Strait, 99 Sv Drake Passage, 25.5 Sv Makassar Strait.... Mass, heat and salt transports across a large number of WOCE meridional and zonal sections were calculated. The heat and salt transports across 35 S are estimated as +0.34 PWt and -18 ktons/sec respectively. The seasonal variations of the heat transport across this section are: -0.50 PWt in Winter, +0.77 PWt in Spring, +0.71 PWt in Summer and +0.01 PWt in Fall. Indonesian throughflow into the Indian Ocean (is close to 25 Sv) ranges between 22 and 26 Sv for different seasons. Seasonal variability of mass, heat and salt transports across the three key sections in the Southern Ocean is discussed.

The freshwater forcing of the thermohaline circulation: Analysis of a coupled GCM

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The hydrological cycle links the oceanic thermohaline circulation with the Earth's water budget. Today's atmospheric freshwater transport makes the Atlantic saltier than the other ocean basins affecting the ocean's circulation and thus in turn the hydrological cycle. We examine the role of the freshwater forcing for the thermohaline circulation by analyzing different quasi-stationary climate states of the coupled circulation model ECHAM3-T21/LSG.

In our control climate, the Atlantic catchment area is a net evaporative region. For the analysis of the hydrological cycle, we compare the water routes for a colder and a warmer climate with the water routes of the control climate. The cold climate is generated by a melt water release in the northern North Atlantic whereas the warm climate comes from a doubled CO_2 concentration in the atmosphere. We find that the water vapour export out of the Atlantic catchment area is enhanced for both the colder and warmer climate states.

It is argued that the enrichment of sea surface salinity along the conveyor belt accounts for a stabilizing effect for the thermohaline circulation. A 700-year integration of the coupled model with doubled CO_2 concentration shows an increase in North Atlantic's salinity reestablishing a circulation strength close to the present day's value. The ocean's water routes in the global model are furthermore analyzed.

THE 48°N ATLANTIC SECTION: CHANGES IN WATER MASSES AND HEAT TRANSPORTS DURING WOCE

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Four repeats of the WOCE/A2 section -situated between the subtropical and the subpolar gyre in the North Atlantic- since July 1993, show a significant interannual variability in the baroclinic structure, i.e. the variability in the intermediate and deep waters. To quantify this temporal and spatial variability we calculated mass, heat and freshwater transports in different density layers and compared them with estimates in layers of neutral density. The eastward propagating Labrador Sea Water LSW stopped cooling in the western basin in 1995, in the eastern basin one year later. A warming period was observed at nearly constant salinity since. At the deep salinity maximum (ca. 2500 db) temperature increased in the eastern basin until 1994 with a slight increase of salinity and density, followed by cooling and a density increase until 1996. Since, we observe a further warming and a density decrease. In the western basin, deep waters continuously cooled until 1996 (0.4°C) with a slight freshening and increase in density. In 1993, a thick layer of Subpolar Mode Water SPMW with a temperature range of 1°C was reduced in the following years to two sharp extrema. In 1997, these have both been 1°C warmer and 0.2 less dense then in the three previous years. Doming of the subpolar gyre and warming of the SPMW is correlated with the breakdown of the NAO in 1995-1996.

THE NORTH ATLANTIC ATMOSPHERE - OCEAN OSCILLATION: OBSERVATIONS OF THE OCEAN'S PARTICIPATION IN A SLOWLY VARYING CLIMATE

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There is growing evidence for the participation of the North Atlantic in a decadally varying North Atlantic Atmosphere - Ocean Oscillation (NAAOO), a phenomenon spanning the tropical, subtropical, subpolar and polar domains. A brief review of the NAAOO covarying atmospheric, sea surface, mixed layer, thermocline and deep water fields is presented, as well as some thoughts on the issues these observations raise and some ideas of strategies for sustained measurements and for critical process studies. This phenomenon involves the simultaneous coupled variability of the Thermohaline Circulation -- the strong meridional overturning circulation of the North Atlantic -- and the strong recirculating gyres of the upper ocean including their gyre - gyre exchanges. It also seems that at mid - latitudes the deep and sub - thermocline circulations may be critically linked in the western boundary current regime, so that deep variability can feed back to alter upper ocean circulation pathways and warm water advection. This in turn may alter the oceanic response to changing forcing from that of Rossby wave adjustment of gyre interior, and thus in a coupled ocean-atmosphere system the time constant and nature of oscillations.

MID-BASIN FLOW IN THE SUBPOLAR NORTH ATLANTIC

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The U.S. WOCE Atlantic Circulation and Climate Experiment (ACCE) supported hydrographic cruises on the R/V Knorr during 1996 and 1997 in the eastern subpolar and subtropical gyres northward of the Azores and southward of Iceland. Subpolar and subtropical waters flow eastward as the North Atlantic Current (NAC) and turn northward into the subpolar gyre, a flow that includes warm and saline subtropical waters branching from the subtropical gyre into the subpolar gyre. This is the warm limb of the warm- to- cold water transformation pathway. While some of this warm flow passes northward into the Nordic Seas, the rest turns westward, ultimately to make its way into the Labrador Sea. By what pathways and flow intensities the eastward flowing NAC waters turn northward and then westward are venerable issues, but remain controversial. These issues are important to resolve, for the associated water mass transformation are central to the thermohaline circulation and regional climate variability. Using a combination of high resolution hydrographic transects, hull-mounted and lowered acoustic Doppler current profiling and a historical hydrographic data base we give an interpretation of the warm-water circulation and transformation within the subpolar gyre with a particular focus on the relation of the flow field to the Reykjanes Ridge.

INTERHEMISPHERIC EXCHANGES OF MASS IN THE ATLANTIC OCEAN

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Two zonal and two meridional hydrographic sections at 7.5°N, 4.5°S, 35°W and 4°W, which were occupied in January-March 1993 in the equatorial Atlantic Ocean, are combined in an inverse model to estimate the circulation and evaluate interhemispheric exchanges of mass and properties. Focussing on the thermohaline circulation, it is shown that, at the time of the cruise, the southward transport of cold water presents an hemispheric asymmetry. North of the equator, the maximum southward transport is associated with the lower component of the North Atlantic Deep Water (NADW) and occurs as a Deep Western Boundary Current. South of the equator the southward transport of NADW is mainly associated with the upper component of the NADW, part of it being found in the eastern bassin. This transport asymmetry is explained by the conversion of lower NADW into warmer water in the equatorial region, and by the conversion of some Antarctic Intermediate Water into upper NADW. As a consequence of the latter conversion, the amplitude of the thermohaline cell increases from 20 Sv to 30 Sv between 7.5°N and 4.5°S. At 4.5°S, the return flow of warm water occurs as a northward geostrophic flow of central and intermediate waters. Part of these water masses upwell in the equatorial current system, so that at 7.5°N the northward flow of warm water mainly occurs in the Ekman layer.

ADCP-BASED OBSERVATIONS OF THE SEASONAL CYCLE OF TRANSPORT THROUGH THE BAB EL MANDAB STRAIT, 1995-1997

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The exchange flow between the Red Sea and Gulf of Aden-Indian Ocean through the Bab el Mandab Strait was measured continuously from June 1995-January 1997. ADCP and conventional current meters and temperature-salinity chain moorings allow an unprecedented look at the magnitude and seasonal evolution of the inflow layer from the Gulf of Aden and the high salinity outflow layer from the Red Sea. The timing, structure, and evolution of the summer mid-depth intrusion of cold, low salinity water into the Red Sea from the Gulf is measured for the complete intrusion cycles of 1995 and 1996. We unexpectedly find the deep outflow still strong in June 1995, with speeds of 0.6 m/sec and transport of 0.4 Sv. From July to mid-September, the deep outflow persists but is attenuated to speeds of 0.2 m/sec and transport of 0.05 Sv. The dominant summer feature, the cold low salinity intermediate layer intrusion, persists for 3 months, and carries approximately 1.7 x 10^{12} m^3 of cold nutrient-rich water to the Red Sea. Computations from the salinity transport allow estimates of basin-wide evaporation rates. The winter regime begins in mid-September, is fully developed by early November, and continues to the end of the first observation in-terval in March 1996. Speeds in the lower layer are 0.8-1.0 m/sec and 0.4-0.6 m/sec in the upper layer. At maximum exchange in mid-February, outflow transport reaches 0.7 Sv. Ubiquitous oscillations in current and salinity at synoptic and intra-seasonal periods appear related to fluctuations in the along-channel wind forcing and perhaps to coastally-trapped waves.

ON EQUATORIAL CURRENTS OF THE INDIAN OCEAN

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Based on array of all available oceanographic observations in equatorial zone (6 N - 6 S) of Indian ocean mean annual and seasonal fields of temperature, salinity and pressure of water were calculated and constructed. Analysis of singularities in the fields allowed to detect the Tareev Current, which is peculiar analog of subsurface equatorial countercurrents in other two "tropical" oceans.

Spatially-temporal structure of Tareev Current and it's connections with a system of general circulation of Indian ocean were considered.

It is shown, that observational data on common and specific features of equatorial currents in different regions allow to introduce the new contribution to study of a nature and structure of the World ocean global circulation.

The work was carried out at support of Russian Basic Research Foundation (Grant N 97-05-64802).

THE SEPARATION FORMULA AND ITS APPLICATION TO THE UPPER WARM LAYER IN THE ATLANTIC OCEAN

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A different way of looking at the meridional warm water (σ_θ < 26.8) flux in the Atlantic is proposed. We consider a northward flowing upper layer, a stagnant intermediate layer and a southward flowing deep layer. By choosing an integration path to begin at one separation point (the Brazil Current separation from South America) and end at another separation point (the Gulf Stream separation) the pressure terms drop out and we obtain a rather simple expression for the meridional upper layer transport (T) that is independent of the pressure field.

Surprisingly, we find the computed warm water transport to be less than one (1) Sverdrup, an amount that is insignificant compared to the frequently quoted values (10 – 20 Sv). This disagreement occurs because the common suggestion that surface Atlantic water flows northward and sinks in high latitude due to wind and high-latitude cooling alone is in doubt. The discrepancy between the two values is resolved when a *low* or *mid-latitude* conversion of intermediate to upper
thermocline water (via upwelling) is added to the model.

THE AAIW GENERAL CIRCULATION IN THE BRAZIL BASIN AND EQUATORIAL ATLANTIC

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49 MARVOR floats launched in 1994, and tracked during two years, give a fine description of mean currents and mesoscale turbulence at 800 m depth.
AAIW, flowing westward near 25°S within the northern branch of the South Atlantic anticyclonic subtropical gyre, splits into two parts when reaching the continental slope near 28°S. Part of it flows northward as an intermediate (depth) western boundary current (IWBC), bordering the slope at least up to 5°N. The other part flows south and finally merge into the South Atlantic current between 40° and 48°S rejoining newer AAIW injected from the Drake passage.
In the equatorial zone, the IWBC retroflects near 2-3°S and part of AAIW is then advected eastward. After a long excursion (at least to 15°W), it comes back westward along the equator.
The IWBC is frequently accompanied by a countercurrent offshore, and sometimes leaves the coast to penetrate into the interior. This leads to an homogeneization in the interior between 21°S and 5°S. Accordingly, mean currents are very weak there.

TRACER STUDIES IN THE SOUTH ATLANTIC ANTARTIC INTERMEDIATE WATER

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Certain Chloroflourocarbons (CFCs) added to ocean surface waters in recent decades are suited to study transfer of surface waters into Antarctic Intermediate Water (AAIW). We use data originating from three zonal "WOCE" sections across the South Atlantic (WHP A8/11.7°S, A9/19°S, A10/30°S), and 6 "SAVE" sections. Because the sections are non-synoptic, the CFC data were time-corrected to a common year.
The northward flowing AAIW is diluted by exchange with the water masses above and below it, by which its properties are changed. One observes in the property distributions a northward decrease in CFC and oxygen but an increase in salinity concentration. A multi-tracer analysis was applied to separate the AAIW into contributions of different source water masses. A meridional CFC budget is calculated by integrating the pure AAIW components and their corresponding CFC signal in space. Due to the transient signal of the CFCs, this enables a mean turnover time of the AAIW to be derived.

Influence of Mediterranean Outflow on the Atlantic Thermohaline Circulation

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The outflow of salty water from the Mediterranean into the Atlantic is thought to contribute to the formation rate and the relatively high salinity of North Atlantic Deep Water, and it has been suggested that it may influence climate in the North Atlantic.

I present results from a coarse-resolution global ocean model coupled to a simple atmospheric energy balance model, and compare the circulation and surface temperatures obtained with and without the effects of Mediterranean outflow.

It is found that including Mediterranean water in the model leads to a warming of the northern North Atlantic by a few tenths of a degree and an enhancement of the NADW outflow by 1-2 Sv.

GEOSTROPHIC TRANSPORT AS INFERRED FROM XBT DATA THROUGH ANALYTIC T-S DIAGRAMS

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In this work we present a procedure aimed at estimating geostrophic velocities and associated transports from XBT data in the Canary Basin. This procedure consists in analysing historical CTD data to obtain analytic T-S diagrams for 2 x 2| boxes in the 25-35|N and 8-35|W domain. These diagrams allow us to determine potential density from temperature alone. Them, form the potential density estimate we can calculate the geostrophic velocity referred to an isopycnal surface, simply by replacing pressure by the Montgomery function. The water transports are finally integrated from the African coast for different isopycnal bands, an water masses budgets are examined.

PRELIMINARY CANARY CURRENT TRANSPORT MEASUREMENTS FROM UNDERSEA TELEPHONE CABLE.

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Cross stream voltage from an undersea sea telephone cable (PECAN2-EXTENSION) connecting Gran Canaria and Tenerife islands are being measured with the aim to give estimates of Canary Current transport. The volume transport of the Canary Current is derived from motionally induced voltage differences (see Larsen 1992, Phil. Trans. R. Soc. Lod.) between Gran Canaria and Tenerife islands. Preliminary results of such measurements will be exposed.

THE WORLD OCEAN THERMOHALINE CIRCULATION CALCULATED BY NEW ADJUSTMENT METHOD

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A new approach called OMMEGA (Ocean Modelling by Method of General Adjustment) was developed to obtain ocean thermohaline circulation characteristics using temperature (*T*) and salinity (*S*) observation data. The essence of the method is that the ocean is divided into many small-scale areas with statistically sufficient data (SSD) and those with statistically not-sufficient data (SNSD). To process the data, a 3DPEM is used with special regeneration procedure which corrects data observed in SNSD areas without smoothing *T, S* data in SSD areas.
First we apply this method using the Levitus T and S data (with resolution 1° x 1° for the World Ocean) to obtain all mutually adjusted characteristics for two seasons (20 climatic vertical levels). Realistic bottom topography and coastlines of all islands with sizes exceeding 1° were included in the model. Then OMEGA was applied to selected areas yielding intensified flow velocities, gradients of *T* and *S*, and sea-surface height.

A new analysis of hydrographic data in the Atlantic and its application to an inverse modelling study.

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Since the late 70's climatologies of ocean properties have been produced by several authors (Reid, 1978, Levitus, 1982) from analyses of historical temperature and salinity measurements. Although these climatologies have been of great help for the scientific community, they have been criticized because they do not reproduce important frontal structures (nearly no North Atlantic Current, no Deep Western Boundary Current) which limits their use in diagnostic estimates of the climatological ocean circulation.

A new climatology is proposed here for the Atlantic with a high vertical resolution that resolves the horizontal/vertical distribution of water masses. The data set used in this analysis contains nearly 640,000 stations including recent WOCE sections. All stations are first vertically interpolated onto 72 standard levels with a maximum vertical spacing of 100m. After a quality check procedure, the validated stations are gridded onto a 1° by 1° grid. The gridding scheme averages all data within a calculated radius of influence. The value of this radius ranges from 50-100 km in coastal regions to 200-450 km in offshore regions. This region-dependent radius prevents the excessive smoothing of frontal structures apparent in previous climatologies.

An ocean circulation estimate is diagnosed from this new climatology using the inverse model of Mercier et al (1993) constrained by mass conservation, potential vorticity conservation, and Ekman fluxes computed from the ERS-1 wind field. Gridded fields, circulation and transports are presented and discussed.

IDENTIFICATION, CHARACTERISTICS AND DYNAMICS OF SOUTHWESTERN ATLANTIC FRONTS

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SW Atlantic fronts and water masses are studied from climatic data (5000 stations), Marathon Exp. (leg. 8), ?METEOR? satellite SST data base (1989-1994) and ?ds277? SST (Reynolds, 1982-1995). Fronts were established by applying a baroclinic ocean model to calculate maximum velocities at 100 m depth. Their location coincide with the surface isotherms: 20,18,15,12,10,7,5 and 3|C. Water masses are analyzed and classified. SA Central Water (SACW) has two types: tropical (TW) and subtropical water (STW), which vertical distribution indicates interfrontal zones. Their surface limits correspond to the above isotherms. We find stable T-S relationships below the friction layer: 20/36.4,18/36.1, 15/35.6, 12/ 35.1,10/34.8,7/34.4 and 5/34.25. These sharp changes of surface depths indicate frontal zones. Both satellite SST data bases show the same modes corresponding to the 18,15,12,10,7, and 5|C isotherms. Gradients >1|C/100 km indicate frontal zones that closely match those isotherms independently of the spatial/time change in the SST field. A new nomenclature of fronts is offered: Principal Subtropical Front (PSTF-18); Subtropical Front (STF-15); Surface Subtropical Front (SSTF-12); Subantarctic Front (SAF-10); Circumpolar Subantactic Front (CSAF-5); and Polar Front (PF-3). The sign of vertical velocities component on the 18,10,5 and 3|C isotherms shows spatial-time stability and correspond to the Main Fronts. The maximum gradient (> 5|C/100 km) occurs at the Brazil Current Front (BCF), and it can be over any subtropical front (STF) depending on the season. A similar behavior is observed for the Malvinas Current Front (MCF). BCF is a part of Brazil-Malvinas Confluence (BMC) where all thermohalines surfaces are the deepest of the SWA. The front defined by Roden (1989) as BCF at the 300-500 m layer is defined by us as Subtropical Front (STF). We present fronts dynamics all along the data bases periods. Minimum mean depth of the pycnocline coincide with the BMC fronts indicating the paths of low-salinity waters into the open ocean.

EFFECTS OF VARIOUSE BOUNDARY CONDITIONS ON THE THERMOHALINE CIRCULATION AND SEA ICE COVER IN AN ISOPYCNAL MODEL FOR THE NORTH ATLANTIC AND THE ARCTIC OCEAN.

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A modefied version of the Miami Isopycnal Ocean Model (MICOM) coupled to an thermodynamic and dynamic sea ice model is set up for the Atlantic Ocean north of 20°S and the Arctic Ocean. The model utilize local orthogonal curvilinear horizontal grid coordinates and 23 isopycnal layers in the vertical. The focus is on the Nordic Seas where the resolution is about 55 km and the maximum grid distance of about 300 km is in the southern Atlantic. The model is initialized from a climatological ocean state and is forced by monthly mean forcing fields. A serie of sensitive experiments is performed with variouse boundary conditions in the South Atlantic and in the Bering Strait, and with changing strength of relaxation towards observed sea surface temperature and salinity. The results from these experiments is discussed.

INTERDECADAL VARIABILITY OF THE NORTH ATLANTIC THERMOHALINE STRUCTURE AND CIRCULATION: COMPARISON OF RUSSIAN WOCE-97 AND THE HISTORICAL DATA.

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Interdecadal changes of thermohaline characteristics and circulation of the intermediate and deep waters of the North Atlantic are considered. The results are based on the comparison of the Russian 1997 survey of 60°N; WOCE AR5 and AR20N sections with the historical data. Significant changes of the T,S properties of the LSW, GFZW and DSOW are found, along with associated changes of the cross section mass and heat fluxes. The earlier determined intensification of the MOC in the 80-s is confirmed. The MOC strengthening is accompanied by the rapid decrease of the recirculation flows and the formation of the well defined two layer structure of the MOC. In 1997 if compared to 50s and 80s the LSW and the CGFZW have freshened and cooled. The DSOW has experienced the warming tendency. The associated changes of the LSW pathways have been found as well.

LARGE-SCALE PATTERNS OF TURBULENT VERTICAL MIXING IN THE BRAZIL BASIN: IMPLICATIONS FOR THE ABYSSAL CIRCULATION

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The rate of bottom water formation requires a vertical mixing coefficient of $1x10^{-4}m^2/s$ in the deep ocean, while most microstructure data yield an estimate an order of magnitude smaller. We have begun to search for this "missing mixing" in the abyssal ocean using the High Resolution Profiler which is capable of full water-column measurements of turbulent dissipation. In addition, we have monitored the spread of a deliberately injected tracer as part of the Deep Basin Experiment. Sections of the vertical diffusivity to and from the injection site reveal a remarkably simple pattern: mixing was uniformly weak over the smooth abyssal plains of the western Brazil Basin and strongly enhanced above the rough topography near the Mid-Atlantic Ridge (MAR). The elevated turbulence extends to 2000-3000 meters above the bottom and is correlated with enhanced velocity finestructure due to tidal-frequency internal waves originating at the bottom. The dissipation increases with depth, which indicates a downwardly divergent diapycnal velocity in the depth range of 3000-4000 m, consistent with the observed tracer dispersion in the vertical. Estimates of the meridional velocity by use of the planetary vorticity balance are in rough agreement with the observed southward tracer displacement. At deeper depths we infer an eastward advection of Antarctic Bottom Water within the fracture zones adjacent to the MAR, which is sufficiently strong to balance the Bottom Water budget for the Brazil Basin. The robust turbulence signal, with its relatively smooth variation over large scales, suggests that full water-column dissipation measurements can tell us much about the abyssal and intermediate water circulation.

MULTIYEAR VARIABILITY OF THE UPPER OCEAN THERMAL STRUCTURE OF THE NORTH ATLANTIC CURRENT REGIME

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Since May 1988 high density XBT-Measurements are carried out along a line from the English Channel to Halifax/New York as a contribution to the WOCE Voluntary Observing Ship Programme (WOCE line AX3). Until now more than 100 sections cover the transition zone between the sub-polar and the sub-tropical gyre of the North Atlantic. Having a temporal resolution of 2 to 10 weeks for subsequent cruises the spatial resolution of XBT-drops varies from 10 to 40 nautical miles, with most of the profiles covering a depth of more than 750 Meters. Normalized monthly anomalies of heat content show consecutive phases of anomalously lows (1988 - 91 and 1994 - 95) and highs (1992 - 93 and since 1996) in the North Atlantic Current regime. This investigation was extended to heat flux estimates by means of recent CTD-data from WHP section A2/AR19 and additional XCTD-sections.

THE STABILITY OF THE THERMOHALINE CIRCULATION IN GLOBAL WARMING EXPERIMENTS.

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A simplified climate model of the coupled ocean-atmosphere system is used to perform extensive sensitivity studies concerning possible future climate change induced by anthropogenic greenhouse gas emissions. Supplemented with an active atmospheric hydrological cycle experiments with different rates of CO_2 increase and different climate sensitivities are performed. The model exhibits a threshold value of atmospheric pCO_2 beyond which the North Atlantic deep water formation stops and never recovers. For a climate sensitivity which leads to an equilibrium warming of 3.6°C for a doubling of CO_2 and a rate of CO_2-increase of 1%/year the threshold lies between 650 ppmv and 700 ppmv.
Moreover it is shown that the stability of the thermohaline circulation depends on the rate of increase of greenhouse gases. For a slower increase of atmospheric pCO_2 the final amount that can be reached without a shutdown of the circulation is considerably higher. This rate-sensitive response is due to the uptake of heat and excess fresh water from the upper-most layers to the deep ocean.

SPREADING OF THE "1988 LABRADOR SEA WATER CASCADE" ACROSS THE NORTH ATLANTIC OCEAN

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Several repetitions of transoceanic WOCE sections A1/AR7 and A2/AR19 from 1991 through 1997 reveal significant and rapid changes in the intermediate layer of the sub-polar North Atlantic. Watermass property characteristics are used to track the recent spreading of a cascade of new modes of Labrador Sea Water (LSW) throughout the northern North Atlantic that started with a series of intensifying deep wintertime convection events since 1988 in the Labrador Sea. The arrival of these LSW vintages in other parts of the North Atlantic is marked by a substantial cooling, deepening, densification and transient tracer increase of the local LSW core. The trans-Atlantic spreading rate leads to surprisingly high mean speeds which are about three to four times higher than previously suggested. This event, as a conclusive evidence for interdecadal climate variability, now comes to an end.

EFFECTS OF WIND AND GEOMETERY ON THE THERMOHALINE CIRCULATION OF AN OCEAN MODEL

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The effects of wind and geometry on the thermohaline circulation and stratification of a P.E. model are studied. We show that the model thermocline contains two distinct dynamical regimes: an adiabatic regime (and a ventilated thermocline) and, beneath this, a diffusive regime (an internal thermocline). The scaling of the overturning circulation with diffusivity is show to depend critically on the presence or otherwise of ekman pumping. We further discuss the maintenance of deep stratification and the overturning circulation in the model. With small but constant diffusivity and a closed (simply-connected) basin the deep model ocean is too homogeneous and the stratification too weak. Allowing periodic boundary conditions over a fraction of the Southern part of the domain serves to trap the densest water at the southern edge, but does not of itself provide deep stratification. Allowing a partially blocked periodic channel robustly provides deep stratification throughout the model domain, well into the opposite hemisphere. This suggests that the deep stratification of the ocean arises through a combination of the production of cold dense water and a partially blocked period Southern ocean that allows the water to spread.

SF_6 AS A TRANSIENT TRACER IN OCEANOGRAPHY

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Sulfur hexafluoride (SF_6) has been used as purposeful tracer to study ocean circulation and convection processes. Its potential as transient tracer, however, may be as great and similar to that of the halocarbons. The temporal trend of the atmospheric SF_6 concentration is well known and shows a significant increase over the last two decades. Two SF_6 data sets including water as well as air samples which were taken in 1997 in the North Atlantic and the Nordic Seas show that the saturation of SF_6 in the surface layer usually is close to equilibrium.
As an example for the potential of SF_6 as transient tracer the North Atlantic data, which cover stations in the Labrador Sea, the Irminger Sea and close to the Rockall Trough, are used to give an upper estimate of the spreading rate of Labrador Sea Water (LSW). The temporal evolution of the SF_6 concentration in the central Labrador Sea is reconstructed by means of a simple box model and compared with the values in the core layer of the LSW to the east and west of the Reykjanes Ridge.
Similar considerations for the Nordic Seas are impaired by increased SF_6 concentrations of the Greenland Sea Deep Water (GSDW) bottom layer which result from a tracer release experiment conducted as part of the ESOP-2 program. However, future observations of this tracer signal could result in valuable information about the spreading of GSDW in the Nordic Seas.

BIFURCATION ANALYSIS OF THE 3-D THERMOHALINE CIRCULATION

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A simple model for the 3-D thermohaline ocean circulation on an equatorial β-plane is presented, describing ocean dynamics in terms of basin averaged angular momenta and basin averaged first and second order spatial density derivatives. It is a low order projection of the Navier-Stokes equations. The boundary condition for temperature is a prescribed heat flux while the (virtual) salt flux is coupled to the SST via a simple parametrization of evaporation.
The bifurcation structure of this model is determined with a numerical continuation technique. It is investigated how the pole-to-pole solutions, known from studies of 2-D thermohaline circulation, transform in the rotating case by increasing β from zero onwards. Variability induced by the increase of β is discussed.
The mechanism responsible for cross-equatorial flow in this simple model is outlined.

THE NORTH ATLANTIC DEEP WATER DEEP WESTERN BOUNDARY CURRENT IN THE MID-BRAZIL BASIN INFERRED FROM MOORED CURRENT METER OBSERVATIONS

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Moored current meter observations obtained at ≈ 18S in the western Brazil Basin between September 1993 and March 1995 are used to investigate the North Atlantic Deep water (NADW) Deep Western Boundary Current (DWBC) and yield the following conclusions. (1) The transport of the NADW DWBC is 39±5 Sv (1 Sv = 1×10^6 m^3s^{-1}). (2) The flow is not directed along the approximate southward trending bathymetry, but is rather toward the southeast, apparently due to blocking effects of the Trindade-Victoria Seamount Chain ≈ 300 km to the south. (3) The volume transport has a seasonal variability of amplitude ≈ 10 Sv with the transport being greatest in the austral summer (January - February) and least in the late austral winter, early spring (September-October). (4) The Antarctic Intermediate Water immediately above, and the Antarctic Bottom Water immediately below also flow in the same direction as the NADW DWBC and transport about 10 Sv and 4 Sv, respectively.

BIFURCATION ANALYSIS OF THE 2-D THERMOHALINE CIRCULATION

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A simple model for the 2-D thermohaline ocean circulation in a double hemispherical basin is presented, describing ocean dynamics in terms of basin averaged angular momenta and basin averaged first and second order spatial density derivatives. It is a low order projection of the Navier-Stokes equations. The boundary condition for temperature is a prescribed heat flux while the (virtual) salt flux is coupled to the SST via a simple parametrization of evaporation.
The bifurcation structure is determined with a numerical continuation technique. It is found that the equatorially symmetric equilibria bifurcate to equatorial asymmetric solutions. Depending on the relative strength of the salt flux, solutions can be found with a robust 2-cell structure. A wedge-shaped dominant cell, covering the largest part of the basin, is situated on top of a wedge-shaped weaker cell. The dominant and the weaker cell feature formation of deep-water near opposing poles. For higher values of the forcing, this stationary equilibrium bifurcates into a periodic equilibrium, with a typical period on the overturning time-scale. A physical mechanism for the symmetry breaking and the transition to a periodic equilibrium is outlined. The model is also run under the traditional mixed boundary conditions (restoring to a prescribed ocean surface temperature and prescribing a salinity flux), and the differences with the flux boundary conditons are discussed.

THE IMPACT OF INTERBASIN EXCHANGE ON THE ATLANTIC OVERTURNING CIRCULATION

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To compensate for NADW export, the Atlantic extracts water from two sources with contrasting water mass characteristics: cold and fresh water entering through Drake Passage, and warm and salty water entering by Agulhas Leakage. However, the exact division of this shallow return transport between both candidates is only poorly known. This composition is not only important for the heat and freshwater balance of the Atlantic: it may also influence the overturning strength directly, as it modifies the energy balance in the Atlantic.
To address this hypothesis, we analysed the climatology of the U.K. OCCAM model and estimated the distributions of heat and salt fluxes through the 70°W and 20°E sections. It was found that the Agulhas region acts as a source of heat and salt for the Atlantic, while the ACC acts as a sink. Based on these results, source distributions of heat and salt were constructed and applied in a zonally averaged model of the Atlantic overturning circulation. The strength and stability properties of the overturning circulation were studied in relation to changes in the source distributions, to assess the impact of changing NADW return flow composition on the thermohaline circulation.

An inverse box model of the nothern North Atlanitc

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From October to December 1994 the WOCE sections A1 (Meteor 30/3) and A2 (Meteor 30/2), forming a triangle between New Foundland, Greenland and Europe, were carried out on a quasisynoptic timescale. The hydrographic data as well as meteorological model data (ECMWF and NCEP/NCAR) were used for the inverse box modelling. The Inverse Method is applied to balance the in- and outflows of this closed box in the area of the Subpolar Gyre. The fluxes taken into consideration are geostrophic, Ekman, interfacial fluxes (mass, heat and salt), and the surface heat and freshwater fluxes. The ability to resolve the circulation of the northern North Atlantic by inverse modelling is tested in different cases (e.g. varying constraints, initial reference level and given fluxes). The resulting surface velocities are compared with the velocities derived from altimeter data.

SEASONAL CIRCULATION AND ASSOCIATED ADVECTIVE FLUXES OF HEAT OFF SOUTHERN BRAZIL AND URUGUAY: MODELING AND *IN SITU* DATA

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We construct an inverse model for seasonal surface circulation in the region off Southern Brazil and Uruguay ($30-35^{\circ}S$; $50-55^{\circ}W$). Little *in situ* data on circulation are available in this area, while a large array of data on SST and surface heat fluxes has been collected. We employ, in particular, the data of the field program COROAS - Brazilian contribution to WOCE. Based on observed seasonal changes of SST along with the observed surface heat fluxes, we compute the advective heat flux as a residual needed to provide for heat budget closure. The fields of advection together with the fields of SST, with the help of continuity equation and boundary conditions, serve to reconstruct velocity on a grid $20' \times 20'$. Perhaps the most intriguing finding of the model is a persistent and energetic northward flow in the shelf, between the coast and the southward Brazil current reproduced by the model in the offshore part of the region. We discuss the origins of this northward motion and its possible relation to the massive freshwater outflow from the Plata estuary. Further, we compare the model results with the data from our recent moored current measurements, virtually the first *in situ* velocity data in the area of this study.

MATHEMATICAL MODELLING OF THE WORLD OCEAN THERMOHALINE CIRCULATION: SOLVABILITY, ALGORITHMS, RESULTS.

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A mathematical model of the World ocean thermohaline circulation is presented. The model is described by the primitive equation system in σ- coordinates. We first present an historic review about the solvability of different models of the ocean circulation. Our goal is to construct a cost-effective flexible model that simulates the large-scale structure of the World ocean. The model uses the evolutionary symmetrized form of governing equations. The computational algorithms are based on the decomposition of a space operator and implicit splitting schemes. We give the results of calculations of the equilibrium states of the global thermohaline circulation with resolution 5*4*10. At the sea surface we specify the seasonal variations and the annual mean values of wind stress, temperature and salinity. The equilibrium oceanic circulation contains self-sustained oscillations with different periods from a few to hundreds of years. These oscillations of the World ocean fields manifest themselves even under the stationary forcing. The experiments show that different circulation regimes exist under identical forcings. The difference depends on initial conditions. This effect is detected, given both the seasonally varying and annual mean values of sea surface temperature and sea surface salinity.

"GLOBAL CHANGE" AT THE BRAZIL–MALVINAS CONFLUENCE: LOW FREQUENCY VARIABILITY REVEALED FROM HISTORICAL DATA

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We used historical SST data to investigate interdecadal and interannual variability off the coast of Southern Brazil and Uruguay. About 300,000 reports from ships of opportunity since 1854 were complemented with the data extracted from global data sets such as COADS and also with recent satellite derived SST data. In this way, monthly series of SST with the duration as long as 141 years have been constructed on a grid $1^{\circ} \times 1^{\circ}$ (although with lacoons in early years). Special attention was given to a winter position of the Brazil–Malvinas front which exhibited large interannual migrations. Periods below 10 years account for more than a half of the energy associated with these migrations. In the low frequency band, significant peaks were found centered at, aproximately, 18 and 47 years periods, there were also indications of a peak at about 130 years. The model made up of a linear trend and isolated harmonic signals of these periods is in good agreement with the "low–passed" data. Everywhere in the region, the series of SST anomalies indicate secular warming at the rate from 0.4°C to almost 1.5°C per 100 years. Otherwise, about 80% of the interannual SST variations resides at periods below 10 years, except on the shelf. In the shelf zone, both the climatic trend and the interdecadal variability are largest in the areas affected by major river-runoff, which may point towards human impact.

OA2 Processes in regions of oceanic time series stations

Convener: Müller, T.J.

Co-Convener: Lukas, R.

OCEAN WEATHER STATIONS TIME SERIES AND CLIMATIC CHANGES

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We present in a consistent manner the entire (NODC/WDC-A) collection of temperature and salinity time series from Ocean Weather Station (OWS) regions. We have used these data to define and support our analysis of upper ocean temperature variability for the 1960-1990 period.

Changes of the OWS location and acquirement of the new observational tools may cause the ingomogenity of the time series. Complex oceanographic conditions and/or their abrupt changes in the OWS location affect the analysis of trend and quasiregular components of the time series. These effects have been carefully studied for the different spatial and time scales.

Evolution of the oceanographic conditions depicted from the OWS time series have been compared with climatic indices (e.g. the North Atlantic Oscilation among others) and the time variability of sea-level pressure, sea-surface and sub-surface temperature fields. Similarities between the leading modes of ocean temperature field and heat storage variability and the OWS time series during 1960-1990s make possible to infer oceanographic conditions for ocean basins back to the 1940's.

INTERANNUAL OCEAN VARIABILITY AT THE U.S. JGOFS BERMUDA ATLANTIC TIME-SERIES STUDY (BATS) AND HYDROSTATION S SITE

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The Sargasso Sea is the site of two long-term ocean time-series; the U.S. JGOFS Bermuda Atlantic Time-series Study (BATS) site (1988-present) and Hydrostation S (1954-present). Physical and biogeochemical observations at both sites provide a unique window on the dynamics of interannual and decadal variability. First we review our observations of the seasonal patterns and interannual variability of mixing, production, biogeochemistry and particle fluxes in the Sargasso Sea. We show that marked changes in upper ocean biogeochemistry have occurred over the last decade, the causes of which may be linked to physical changes in the subtropical gyre, increase in the atmospheric deposition of dust and the Northern Atlantic Oscillation (NAO). There also have been changes in the cycling and fluxes of carbon and the exchange of CO_2 between ocean and atmosphere. We find that the rate of increase of oceanic inorganic carbon (total carbon dioxide) has increased at a rate of 1.6 moles kg year, double the rate expected from the observed increase in atmospheric CCO_2 due to anthropogenic input. If continued, this will reduce the oceanic sink of CCO_2 in the Sargasso Sea. We also estimate the inventory and penetration depth of anthropogenic CO_2 in the Sargasso Sea using the the δC^* method of Gruber et al., 1997. Finally, we report marked changes in deep water phosphate, PO_4* and silicate concentrations at BATS over the last decade. Over time, the percentage of deep water having a Southern Ocean source has increased relative to Northern hemisphere source, reflecting a reduction in the supply of North Atlantic Deep Water (NADW) into the subtropical gyre.

EUROPEAN STATION FOR TIME-SERIES IN THE OCEAN CANARY ISLANDS (1994 - 1997)

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The European Station for Time-Series in the Ocean Canary Islands (ESTOC) is positioned at 29 10'N, 15 30'W, about 100 km to the north of the island of Gran Canaria in the eastern boundary current of the Subtropical North Atlantic gyre, and it has a depth of 3600 m. The station was started as a cooperative project between two German and two Spanish Institutions, named in the authorship. Establishing temporal time-series in the ocean is an important aim of both the WOCE and the JGOFS Science Plans and the station was established taking as a reference two already existing stations in Subtropical waters, the Bermuda Atlantic Time-Series (BATS) and the Hawaii Ocean Time-Series (HOT). The station activities can be assembled in three main blocks : continuous records of instruments moored at the station, monthly measurements at the station with the execution of a basic program of observations and sampling and regional process studies ; the main objective is to determine the representation of the observations made according to the processes that are found at the station within the context of the subtropical gyre in this area. This paper presents the work carried out during the "first" four years at each block; some preliminary results are shown too to try to provide an overall view of the project.

PRESENT STATUS AND FUTURE OF JGOFS-KERFIX TIME SERIES STATION (50°40S - 69°25E)

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Between January 1990 and March 1995, the research project KERFIX undertook the first regular non-coastal multiyear acquisition of parameters related to the carbon cycle in the Southern Ocean at a time series station located at 50° 40' S - 68° 25' E, 60 miles southwest of Kerguelen Islands. The objectives of KERFIX were 1) to monitor the ocean/atmosphere CO_2 and O_2 exchanges 2) to understand the seasonal and interannual variability of fluxes of carbon and associated elements at this location. We present a survey of the KERFIX programme and results of the temporal evolution of nutrients and biological parameters. Chl-a concentrations are always low, with weak summer maxima (< 1.2 mg.m^3). Whereas nitrate concentrations are never depleted, silica can fall down to values <8 µM in summer. These results are discussed in terms of limitation of phytoplankton growth. Future projects around the KERFIX time series station will be also presented.

AN OVERVIEW OF OCEANIC CO_2 VARIABILITY AT JGOFS-KERFIX TIME SERIES STATION (50°40S - 69°25E)

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The upper-layer oceanic carbon cycle is assessed thanks to the data obtained from the monitoring of JGOFS-KERFIX time series station between 1990 and 1995. An overview of carbon data analysis and modelling studies is presented.
Dissolved Inorganic Carbon is low in summer period due to the biological uptake of CO_2 and increases of 25 mmol/m^3 through winter following the mixing of the surface layer with CO_2 enhanced subsurface waters. Total Alkalinity presents a low seasonal signal about 10 méq/m^3 which reveals a biological system dominated by diatoms. Thanks to these observations, seasonal budgets are calculated to assess the impact of the physical and biogeochemical processes on CO_2 variations. On an annual basis, the physical processes are balanced by the biological uptake.
Combining 1D models of the mixed-layer and the observations, several investigations are performed : identification and quantification of the biological and physical processes in the upper-layer carbon cycle at KERFIX, impact of climatic anomalies on air-sea CO_2 and O_2 fluxes and anthropogenic CO_2 uptake.

A STRING DEPTH–GAUGE FOR COMPLEX MONITORING OF SEAS AND OCEANS

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One of the main requirements for complex instrumentation to study seas and oceans is to provide its accuracy and stability. Depth-gauges with the frequency output signal can operate autonomously and satisfy such conditions. We have developed depth-gauge based on the string method that is able to continuously record depth of the dipped both stationary and towed buoy. The used string (tape) and elastic element are made of an unbroken material. The main advantages of such a depth-gauge are as follows: digitized output signal; small power using; high sensitivity (up to 0.5 Hz/cm); linearity in a depth range up to 500 m; long term stability of order 0.02 % per year; practical insensitivity to ambient temperature variations. We discuss some technical details, preliminary results, and further possibilities of the developed string depth-gauge.

LONG-TERM HYDROGRAPHIC VARIATIONS OBSERVED IN THE HAWAII OCEAN TIME-SERIES

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The Hawaii Ocean Time-series (HOT) program started in October 1988 with the purpose of making monthly observations of the physics, chemistry and biology of the water column at a deep-water station (22 45'N, 158 W) north of Oahu, Hawaii. The dominant interannual signals in the near-surface layer are related to local forcing variations associated with the El Ni±o-Southern Oscillation phenomenon. Near-surface salinity reflects most clearly the interannual variations of surface forcing. Currents measured with a shipboard acoustic Doppler current profiler have revealed the existence of a near-surface mean flow to the west-northwest along the Hawaiian Ridge at 158 W which exhibits a weakening in the recent years. Within the water column, there are 3 hydrographic features which dominate the mean profiles: These features are the shallow salinity maximum in the upper thermocline, the salinity minimum associated with the North Pacific Intermediate Water mass, and the dissolved oxygen minimum associated with the Antarctic Intermediate Water mass. So far, one of the biggest surprises is the monotonic trend towards lower values of dissolved oxygen in the Antarctic Intermediate Water. That trend may be associated with trends in other properties and other portions of the water column which are masked by other, more energetic, variability. A freshening trend has been observed in the salinity maximum in the past few years. The large-scale context of these low-frequency variations will be discussed.

SEASONAL VARIATIONS AND HIGH FREQUENCY EVENTS OF THE CO_2 PARTIAL PRESSURE AT THE OCEAN SURFACE : A NUMERICAL APPROACH AT THE DYFAMED STATION (NW MEDITERRANEAN SEA)

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At the ocean surface, the CO_2 partial pressure is driven by thermodynamical, biological and dynamical processes. At mid-latitudes, these processes show a significant seasonal cycle, mostly forced by air-sea interactions, and mixed-layer dynamics. At the beginning of the 90's, in situ JGOFS studies, as well as other related programmes, have clearly shown that high frequency p CO_2 variability could be almost as large as seasonal and large scale variations. In 1995 and 1996, the CARIOCA buoy was set up at the France JGOFS DYFAMED station, located in the NW Mediterranean Sea between Nice and Calvi. Hourly SST and pCO_2 data have been obtained during different periods. Besides the general seasonal trend, very high frequency events can be observed in these records, associated to strong wind bursts (Mistral). A simple bio-geochemical model in nitrogen has been coupled to carbon. Years 1995 and 1996 are then simulated with atmospheric forcing coming from the ARPEGE model (French Met. Office) with a time resolution of 6 hours. Although the quality of the forcing is not entirely satisfying, the global behaviour of the model is correct when the results are compared to the CARIOCA data. The influence of high frequency atmospheric forcing is emphasised by comparing a simulation forced by smooth atmospheric fields.

HIGH FREQUENCY VARIABILITY OF PCO_2 AND CO_2 AIR-SEA FLUXES AT TWO JGOFS STATIONS : DYFAMED (WESTERN MEDITERRANEAN SEA) AND BATS (SUBTROPICAL NORTH ATLANTIC GYRE)

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From january 1997 until now (december 1997) a CARIOCA buoy has been installed at the french JGOFS DYFAMED station, located in the N.W. Mediterranean Sea. The PCO_2 range over the year 1997 extends between 250 µatm and 450 µatm. The main features describing the seasonal variability of PCO_2 at the sea surface are : 1) an intense wind induced mixing in january-february with deep, enriched CO_2 and cold water (PCO_2 close to 400 µatm, surface temperature close to 13°C), 2) a large, rapid drawdown of PCO_2 values (PCO_2 close to 280 µatm) occuring in late february-early march, associated with the onset of active spring blooms, 3) heating in early summer, which brings PCO_2 values up to 450 µatm and SST to 24°C. However, the thermodynamic effect, which is mainly responsible for the observed increase of PCO_2, is partly compensated by a consumption of carbon during the months of july and august, and 4) as the result of the subsequent cooling in the fall, PCO_2 and SST values are taken back to 250 µatm and 13°C.

A similar experiment has been conducted at the US JGOFS time series station BATS at Bermuda. Measurements have been made by a Carioca buoy during the months of june and july and have just started again in december. We will compare the data obtained at both stations, DYFAMED and BATS, as they have similar thermodynamic and biogeochemical characteristics : large seasonal thermal cycle, winter mixing, oligotrophic environment.

GEOCHEMISTRY AND MODELING OF SEDIMENT TRAP TIME SERIES FROM THE MEDITERRANEAN SEA.

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During the sinking of marine particules through the water column, interactions occur betwen the solution and the particles of different sizes. Specific elements can be used to trace these processes : Al for aggregation/desaggregation of particles; Ba and Mn for biogenic/authigenic formation. We analysed sediment trap material collected at 200 m and 1000 m at the DYFAMED site (43°25'N-07°54'E) during the 1994 time series. The fluxes range from 0.63 to 10.3 mg/m2/d for Al ; from 0.005 to 0.19 mg/m2/d for Ba and from 0.0001 to 0.1 mg/m2/d for Mn. Data show that elements and mass fluxes are higher at 1000 m than at 200m. We develop a model "COLDO" that simulates particle flux variations with time from the bottom of the photic zone down to the sea floor. It takes into account interactions between solution, small particles and large sinking particles through first order adsorption/desorption and aggregation/desaggregation reactions. The rate constant of these processes can vary with depth and time. Boundary conditions of the model are the fluxes measured at 200m. Comparison between simulated and measurements fluxes at 1000m will be presented and discussed.

SEASONAL TREND IN PARTICULATE CARBON FLUX AT THE TIME-SERIES SITE KERFIX IN THE SOUTHERN OCEAN

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In the framework of the Southern Ocean France-JGOFS programme KERFIX vertical fluxes of particulate material were measured in the Indian Ocean sector of the open Southern Ocean from April 1993 to January 1995. Particles were collected using a moored sediment trap (PPS5 Technicap, 1 m^2 surface opening) deployed below the euphotic layer (at 200 m, bottom depth 1755 m) Southwest of Kerguelen Island by 50°43.5' S and 68°25.8' E. The time resolution of sampling was one month in winter and 7 to 10 days in the more productive months of spring and summer. Mass and carbon fluxes presented a very clear seasonal trend with low fluxes throughout winter (June to October) increasing thereafter progressively to become relatively important in summer (January to April). The highest mass and carbon fluxes were recorded in February with 207 and 14.6 mg $m^{-2} d^{-1}$, respectively. Annual Annual particle flux was estimated to be 11.2 g $m^{-2} y^{-1}$ and annual carbon flux at 0.9 g $m^{-2} y^{-1}$, of which 80% was organic carbon. The contribution of phytoplankton derived material to carbon flux was most important in January-February whereas fecal material produced by zooplankton was most important in February and early March (up to 3 mg C $m^{-2} d^{-1}$ or 51% of total C flux). The present data emphasises the very strong seasonal signal on particle production and export in the open Southern Ocean.

PARTICLE FLUX MEASUREMENTS AT ESTOC

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The ESTOC (European time-series in the Ocean, Canary Islands) is located 100 km north of Gran Canaria in the eastern extensions of the subtropical North Atlantic gyre. The monthly sampling schedule started there in 1994, and particle flux has been determined with moored particle traps at the station since fall of 1991. So far, a five year record of particle flux, mainly from two depths (1km and 3km) has been collected. In all years, the dominant signal was the winter bloom and related particle sedimentation maxima, which varied interannually. Consistently, deep-water particle flux was considerably greater than shallow water particle flux indicating deep lateral advection of particulate matter. A recently published study (Neuer, Ratmeyer, Davenport, Fischer and Wefer, Deep-Sea Res. 44, 1451-1466) points to filaments as possible carriers of particulate matter from the coastal region into the collection area of the deeper traps. In 1996, we determined for the first time particle flux rates also in 700 m depth in addition to the 1 and 3 km traps. Particle flux measured in the shallower trap was for the most part higher than the rate determined in 1000 m depth, but still lower than in 3000 m depth. In addition, we were able to determine particle flux with drifting traps in 200 m depth on three cruises during the same year. The flux data determined with the drifting traps matched mostly those obtained in 700 m depth with the moored traps, but exceeded the rate determined during the winter sedimentation maximum (about 200 mg m-2 d-1 compared to about 70 mg m-2 d-1) in February 1996. It is possible that the drifting trap deployed in February collected a sedimentation puls that was not resolved by the moored trap because of the longer collection interval.

TRENDS AND LONG TIME VARIABILITY OF OCEAN PROPERTIES AT OCEAN WEATHER STATION M IN THE NORWEGIAN SEA

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50 years (1948-97) of oceanographic data collected at Ocean Weather Station MIKE at $66°N2°E$, have been examined for trends and interannual variability. The data for the upper layers show a general trend of cooling and freshening of the upper layers since about 1960. The upper-layer analysis also reveals a strong cooling and freshening on a shorter timescale starting in 1991, and the salinity- and temperature values are now below the levels observed in the late 70's (when the "Great Salinity Anomaly" passed through). The intermediate waters show a significant decrease in salt content between the years 1976 and 1978. The data also indicate a rapid warming in the deep water of the Norwegian Sea starting in the late 80's.

THE ENSO SIGNAL AND THE ANTARCTIC CIRCUMPOLAR WAVE EVIDENCED BY KERFIX TIMES SERIES DATA

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Monthly hydrological data obtained between 1990 and 1995 at the JGOFS-KERFIX time series station (50°40S - 69°25E) give us for the first time the mixed layer data in the Southern Ocean (SO) proving the oceanic teleconnection between Pacific, Atlantic and Indian Ocean through the Antarctic Circumpolar Wave (ACW).
The anomalies of mixed layer depth (MLD), mixed layer temperature (MLT) and salinity shows a clear tendency of climatic variation. The temperature decreased, while the salinity, density and MLD increase significantly since 1993. The low interannual frequencies calculated using Kerfix data are correlated to the ENSO anomalies signal of precipitation, atmospheric pressure and SST calculated using ECMWF global data and extracted for the Kerfix location: i) SST ENSO anomaly and MLT anomaly at Kerfix are warmest in 1992 and coldest in 1994; ii) decrease of the precipitation is associated to the Kerfix increase salinity. The correlation between ENSO wave signals and the MLD properties anomalies at Kerfix shows that interannual variability observed at Kerfix can be explained by the propagation of ENSO (originated in the Subtropical South Pacific Ocean) go toward the Indian SO through the ACW. This teleconnection which is unique in climate dynamics is likely playing an important role in climate regulation and oceanic dynamic beyond the SO. Because the SO may dominate much of the oceanic response to global warming, it is important that we maintain long term monitoring programs aimed at understanding fundamental mechanisms and detecting changes. Kerguelen Island presents a unique opportunity to carry out such an effort.

THE 17-YEAR TIME SERIES FROM MOORING KIEL 276 IN THE EASTERN NORTH ATLANTIC

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A mooring site for long-term measurements was established in 1980 on position 33°N, 22°W in the eastern North Atlantic at a water depth of more than 5000 m. The mooring was replaced once a year and carried up to 8 current/ temperature meters, distributed between about 200 m and the bottom. The project was possible because use could be made of German research vessels operating in the larger region or transiting to the equatorial or southern Atlantic. The mooring location is in the region of the Azores Current and thus in the North Atlantic subtropical gyre. The observations, despite some occasional gaps at certain depth levels, reveal long-term changes on timescales from a few months to several years. High-energy events on the month-timescale are common, but occur irregularly. They may be due to frontal meanders or mesoscale eddies. In some cases they were identified as signals related to Mediterranean Water lenses (Meddies). The kinetic energy of fluctuations is much larger than the energy of the mean currents, but the barotropic and baroclinic components are of similar magnitude. Results from these observations will be presented in the form of time series, modal components and spectra, and will be related to CTD measurements from this site obtained during the period of the moored observations.

WATERMASSES AND CURRENTS IN THE AREA OF THE "ESTOC" TIME SERIES STATION

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The "European Station for Time Series in the Ocean Canary Islands" (**ESTOC**) is located about 100 km north of the Canary Islands at 29°10'N and 15°30'W. The marine system in the Canary Basin is dominated by the subtropical gyre recirculation, the inflow of Mediterranean Water, upwelling processes along the African shelf and a particle transport which is influenced by Saharan dust
To determine the mesoscale variability as well as the seasonal and interannual variations of the marine environment within the Eastern Canary Basin hydrographic-sections were repeatedly carried out. Two zonal sections, one along 32°15'N between the African coast and Madeira and the other one along 29°N between La Palma and the African shelf, are combined with a meridional section along 18°W between Madeira and La Palma to obtain a closed hydrographic box.
Results from these hydrographic sections will be presented together with results from shipboard and lowered ADCP data and timeseries from the ESTOC currentmeter mooring.

Decadal variability of subtropical mode water, atmospheric forcing & feedback

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Using the Station 'S' time-series of potential vorticity (PV) at Bermuda, the decadal changes in PV in the subtropical mode water (STMW) locally found in the western subtropical gyre (18 degree Water) are used in a correlation analysis to examine the atmospheric forcing over the N. Atlantic. The fluxes associated with decadal changes in the STMW are large scale and 180 degrees out of phase between the western and both the eastern subtropical and subpolar gyres. The STMW response is as one would expect from diabatic forcing with no phase lag, i.e., the PV is low (high) when the buoyancy flux anomaly is large (small). Thus, one might anticipate that decadal changes in STMW in the western subtropics will be anticorrelated with those in the Madeira Mode Water, a major STMW of the eastern subtropics. Furthermore, the phase relationship between surface forcing, mode water production and Gulf Stream path could play major role in defining a mechanism and time-scale for a coupled ocean-atmosphere feedback which could explain some important aspects of the North Atlantic Oscillation.

VARIABILITY OF THE NUTRIENTS CONCENTRATION AT ESTOC (1994 - 1997)

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The European Station for Time-Series in the Ocean Canary Islands (ESTOC) includes the nutrients determination (nitrates + nitrites, phosphates and silicates) within its regular observational program. This poster shows the first results of the analysis made along the four years that the station has been visited to these days, grouped in two blocks. In the first block it is included the surface data down to 200m deep, where the annual signal prevails ; the second block shows the results from 200m to the bottom (when possible) or until the maximum depth sampled at each case, where the prevailing signal corresponds to the interaction between the intermediate water masses, specifically Mediterranean and Antarctic Atlantic (AM and AAI), which are very well marked by their characteristic values of nutrients concentrations. A comparison is also performed between the encountered variability and the registered variability detected in the preexisting nutrients data in the area.

OA3 The North Atlantic Oscillation: decadal variability in ocean and atmosphere

Convener: Hense, A.
Co-Conveners: Rahmstorf, S.; Reverdin, G.

NORTH ATLANTIC OSCILLATION CONNECTIONS WITH THE TROPICAL ATLANTIC SST DIPOLE

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The relation between the North Atlantic Oscillation (NAO) and the tropical Atlantic SST dipole has been investigated using sea surface temperature (SST), zonal and meridional wind components and sea level pressure (SLP) taken from the data set of Da Silva et al. (1994) for the interval 1945-1993. A NAO index has been defined as the first principal component of SLP anomalies from the North Atlantic area north of 20° N. The time evolution of the SST pattern corresponding to the best canonical correlated mode of SST and meridional wind anomalies from the tropical Atlantic is taken as a SST dipole index. The low frequency behaviour of the 2 phenomena is similar for the analysed interval suggesting the existence of a coupling mechanism between them on the decadal time scale. The tropical dipole may influence the NAO development forcing changes in the position and intensity of the extratropical atmospheric jet stream. The NAO could in turn modify the structure of the SST dipole through the fluctuations in the trade wind system.

OA3

THE NORTH ATLANTIC OSCILLATION AND ITS IMPRINT ON PRECIPITATION AND ICE ACCUMULATION IN GREENLAND.

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Interannual to decadal fluctuations in net precipitation and ice accumulation are examined over Greenland. It is shown that in western central Greenland these fluctuations are correlated with the North Atlantic Oscillation. The analysis is based on two complementary data sources: A highly resolved net precipitation and accumulation history over 15 years derived form the reanalysis data of the European Center for Medium range Weather Forecast and a composite ice accumulation record calculated from five different ice core data sets in central Greenland. It is suggested that western central Greenland snow accumulation is a good proxy for the NAO index with the potential for the reconstruction of a long time series.

SIMULATIONS OF NORTH ATLANTIC STORM TRACK VARIABILITY

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A two-part study is undertaken of the North Atlantic storm track in the context of the North Atlantic Oscillation. In the first part the SVD approach is applied to co-examine the statistical characteristics of the SST anomaly field and the 500 hPa geopotential and storm track fields. (The data base comprises the monthly and fortnightly Northern hemisphere fields derived from NMC data sets). Simultaneous and lagged SVD analyses serve to extract the leading SST anomaly patterns, together with their counterparts in geopotential height and storm track position, as well as to identify periods of strong air-sea interaction.

In the second part a sequence of monthly simulations with an operational mesoscale NWP model (the EM of the German weather service with the simulated evolution relaxed at the lateral boundaries to the ECMWF reanalysis fields) is used to provide an indication of the amplitude and structural changes resulting from the imposition of the pre-selected SST anomaly patterns.
Also heuristic experiments with a more idealised representation of the NH reproduce key features found in the SVD patterns, e.g. the sensitivity to changes in strength and location of the main SST gradient and the location of the North Atlantic storm track.

EFFECTS OF THE NAO ON THE STRUCTURE AND DISTRIBUTION OF WATER MASSES IN THE NORDIC SEAS

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Several time series in the Norwegian Sea indicate a general upper layer decrease in temperature and salinity since the 1960s. Time series at Weather Ship M, from Russian surveys in the Norwegian Sea, Icelandic standard sections as well as Scottish and Faroese observations in the Faroe-Shetland area, have similar trends and show that most of the Norwegian Sea is affected. The reason is mainly increased freshwater supply from the East Icelandic Current. As a result, temperature and salinity were in 1996 lower than during the Great salinity Anomaly in the 1970s. There is evidence of strong wind forcing whereas the NAO winter index is highly correlated with the lateral extent of the Norwegian Atlantic Current. Circulation into the Norwegian and Greenland basins of Atlantic water is strongly reduced while circulation of Arctic and Polar water is increased. This affects the water mass structure in a much wider sense by reduced deep water formation and increased supply of Atlantic water into the Arctic Ocean.

LOW-FREQUENCY NAO FLUCTUATIONS IN THE ECHAM4/OPYC3 COUPLED AOGCM

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Decadal-scale (15-30 year period) variability of the North Atlantic Oscillation (NAO) is found in a 300-year control integration of a coupled ocean–atmosphere GCM (ECHAM4(T42, L19) + OPYC3). The cycle is manifest both in atmospheric and oceanic parameters. One of the contributing processes is anomalous Ekman pumping into the central parts of the subtropical North Atlantic during the positive NAO phase which leads to a spin up of the subtropical gyre circulation. Northward transports of warm and salty waters within the Gulf stream system and increased formation of deep water in the Greenland area lag about 5 years behind the positive NAO extremes, possibly due to the ocean's inertia. Simultaneously, intensified atmospheric eddy activity in subpolar regions is associated with freshened surface waters of the Iceland and Norwegian Seas which gradually weakens the thermohaline circulation. The relevance of ocean dynamics for the swing from one NAO phase into the other is discussed.

RELATIONSHIP BETWEEN THE NORTH ATLANTIC OSCILLATION AND THE INTERANNUAL VARIABILITY OF ATLANTIC-EUROPEAN CLIMATE

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The Singular Spectral Analysis technique is used to identify quasi-periodic oscillations contained in the North Atlantic Oscillation (NAO) variability over a period of 140 years. Several stable oscillations are identified, both using monthly time series and winter averages, notably the 3.5 and 6 years oscillations. These oscillations have been recognised in other meteorological time series and are therefore considered to be real. In order to elucidate the mutual influence of the atmosphere and ocean in the sector. the NAO is related to the Sea Surface Temperature (SST) of the North Atlantic Ocean via Canonical Correlation Analysis for different time lags Adiagnosis of storm activity over the Atlantic-European Sector is performed using a high resolution limited area model for periods of enhanced activity of the NAO and/or SST forcing. The effects of the NAO in the North Atlantic Sector are also evaluated by examining the differences in the distribution and intensity of atmospheric depressions.

LONG-TERM TRANSPORT OSCILLATIONS ON THE NORTHWEST EUROPEAN SHELF CALCULATED FROM A 39-YEARS NUMERICAL CIRCULATION MODEL RUN

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Results of a baroclinic 3-D numerical circulation model are present. The model domain covers the northwest European shelf and simulates the period from 1955 to 1993, i.e. a 39 years period. The horizontal grid spacing is aproximately 20 x 20 km and in the vertical direction a maximum of 12 layers is used. The thickness of the layers increases gradually with depth. The model is forced by monthly climatological mean temperature and salinity distributions, the M2 tide at the open lateral boundaries, and 6-hourly meteorological forcing data, i.e. air pressure and wind stress distributions.

Vertical intergrated water mass transports through selected sections in the North Sea are presented as long-term power spectra and auto spectra. Additionally long-term dependencies of water mass transports between these selected sections are discussed by means of calculated cross spectra.

The main conclusion from these time series analyses are prominent peaks for periods of 8 and 17 years. Obviously these periods correspond to peaks in the NAO. Presently the transfer mechanisms are not fully understood.

INTERDECADAL TRANSPORT CHANGES ALONG THE NORTH ATLANTIC SUBPOLAR/SUBTROPICALBOUNDARY

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Time series of density structure in the central Labrador Basin and the central subtropical gyre (Bermuda) combine to form a baroclinic transport index for the eastward flow between these gyres. This index is an oceanographic analogue to the atmospheric North Atlantic Oscillation (NAO) index. In the upper 2000 meters of the central subpolar gyre, density changes reflect the time history of Labrador Sea Water (LSW) convection intensity. In the western subtropical gyre, density changes reflect in part the temperature history of local convection -- the Eighteen Degree Water -- and half the heaving of the thermocline and the expansion or contraction of LSW impact on the water beneath the thermocline. An interdecadal oscillation in transport results, which ranges approximately 20 megatons/sec from peak low to high, amounts to ~60 megatons/sec +/-15% of the Gulf Stream/North Atlantic Current system and derives equally from changes in the subtropical and subpolar gyres. This cycle appears to lag the atmospheric NAO index by a few years. The transport oscillation also demonstrates a coupling between the upper ocean and the deep water: half of its magnitude reflects a strengthening of the shear below 1000 meters. These upper deep waters thus have impact on the upper ocean transport field and on the heat transported poleward by the currents.

THERMAL VARIABILITY OF THE NE ATLANTIC OCEAN

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"ACURATE" (African Coastal Upwelling Research, Analysis and Thematic Experiments) is a new European International long-term programme launched during summer 1997. Part of this Programme is devoted to the investigation of thermal variability of the NE Atlantic Ocean located between 5-45N and 25W - coast of Africa and Europe. 1982-1992 weekly satellite SST data set has been analysed to study seasonal variability of SST field, variance, SST gradients (thermal fronts), mean SST, SST difference between coastal and oceanic waters at 100-500 km distance. The study has been coupled with analysis of seasonal variability of the wind stress and of total heat flux. The capes Blanc and Ghir, and south-western area off the Gibraltar Strait were found to be distinct by SST regime.

DECADAL BUOYANCY FORCING IN A SIMPLE MODEL OF THE SUBTROPICAL GYRE

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Liu and Pedlosky's (1994, herafter LP) simple two-layer model of the ventilation of the subtropical gyre is used to understand the role of buoyancy forcing in determining the variability in the permanent thermocline at the decadal timescale. The model reproduces the Stommel demon and is forced by a prescribed displacement of the first layer's outcrop line. The surface buoyancy flux is diagnosed from the buoyancy budget of the mixed layer. In contrast to LP, the decadal variability is simulated by modulating the seasonal migration of subduction line. For realistic values of the forcing parameter, the variability in the ventilated thermocline is weak but significant, with an interface displacement of the order of 20 meters. The model is generalized to the case of a broad band forcing and the ventilated thermocline response to a stochastic buoyancy considered.

TEMPORAL CONNECTION AND SPATIAL STRUCTURES OF COUPLE MODES OF 500-MB HEIGHT AND SST ANOMALIES FOR WINTER IN THE NORTH ATLANTIC

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Change of a time lag between atmospheric forcing and ocean response and transformation of their most coupled spatial structures as dependent on timescales of considered data are investigated. To do this, singular value decomposition (SVD) analyses of winter SST and 500-mb height (H_{500}) anomalies with time lag between them in North Atlantic were performed. It was established for monthly mean H_{500} and SST fields that the evolution of a SST anomaly is behind of atmospheric forcing for one-half month. This time lag is described quite well by a simple model of SST anomaly that couples half-month shift value with one-quater of 2-month period of oscillation. This shows that significant oscillations with periods of about two months that are present in the midlatitude atmosphere. In addition, fluctuations with timescales less than one month may artificially manifest themselves as an oscillation with 2-month period which is Nyquist's cut-off period for monthly mean data. Among this last oscillations lagged SVD analyses for daily data isolate oscillations with time–spatial parameters corresponding to blocking conditions in the North Atlantic. It was examined also how the spatial structures of H_{500} and the SST vectors of the first SVD mode are revealed good resemblance with results of analyses of observational data.

Did the Denmark Strait overflow intensify in 1996-97?

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S. Bacon has recently described observed variability of transport of the Denmark Strait Overflow Water (DSOW) in the deep western boundary current (DWBC) in the Irminger Basin, southeast of Cape Farewell (CF), Greenland. His estimates are for the most part level of no motion geostrophic, but a good case is made for a link to absolute transport changes. His analysis shows DSOW transports that are relatively weak 1955-67, relatively strong in 1978-90, and relatively weak again 1991-96. The U.S. ACCE program provides hydrographic and ADCP measurements in the CF area in Nov. 96 and May 97, and in Nov. 96, May 97 and Oct. 97 at a location farther north off Angmagssalik (ANG), the site of earlier moored measurements by R.R.Dickson. S. Bacon has provided a late Aug. 1997 CF section. At ANG we find that the DSOW baroclinic and ADCP referenced transports progressively increased over the period Nov. 1996 - Oct. 1997, more than doubling. An less substantial increase was found at CF, from low values similar to Bacon's 1991-96 estimates, to values on the low side of the range his high transport group from 1978-90. We find at ANG accompanying the transport increase is a strong freshening of the DSOW. A hint of this freshening is seen at CF accompanying the transport change there. It is known that the NAO index was high in the early 1990's but shifted to very low in winter 1995-96, and then to neutral in winter 1996-97; changes in wind and buoyancy forcing of the Nordic Seas and subpolar gyre will track this shift. Is the DSOW system accelerating in delayed response, by some combination of changes in water mass transformation rates and intensity of wind/buoyancy-driven circulation?

MULTIDECADAL VARIABILITY OF THE COUPLED TROPOSPHERIC AND STRATOSPHERIC CIRCULATION AND ITS CONNECTION TO THE NORTH ATLANTIC CIRCULATION

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The coupled atmosphere-ocean model ECHAM3/LSG T21 shows an irregular oscillation in the time series of the zonal mean zonal wind in winter on decadal time scales with a period of 70 to 90 years.
Based on this time series two distinctive modes are selected, one accounting for a strong stratospheric polar night jet, the other for a weak one.
These two modes show completely different features in the troposphere: when the zonal wind is strong, the Aleutian low is weakened and a positive North Atlantic Oscillation (NAO) index prevails. In the Pacific stronger trade winds appear and the subtropical high moves north-eastwards and weakens the Aleutian low. In turn the trough over the Okhotsk Sea is deepened. This zonalization of the midlatude circulation leads to a stronger stratospheric polar vortex, allowing the positive phase of the NAO to prevail.
During periods of weak zonal winds the Aleutian low is anomalously strong and the NAO index is negative. This disturbs the polar vortex because of adiabative sinking and warming in the vicinity of the low pressure systems. When weak zonal winds are predominant the velocity potential shows a slightly weaker and zonally shifted Walker circulation.
Possible causes for the forcing of this long-term oscillation will be discussed.

THE NAO IN A LONG SIMULATION WITH A COUPLED AO-GCM AND ITS INTERACTION WITH NORTH ATLANTIC SST

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A very long simulation of 800 yrs with the coupled AO-GCM ECHAM3-T21/LSG has been investigated. The first mode of interannual and interdecadal variability of the northern hemispheric geopotential height resembles the NAO and shows a strong coherency to the north Atlantic sea surface temperature (SST) anomalies similar to observations. An ensemble of atmosphere-only time-slice experiments was performed with identically prescribed SST and sea ice coverage taken from the coupled run. Multiple integrations starting from different initial states are a powerful tool to investigate the ratio of SST induced to internally generated variability. The fraction of variability explained by SST forcing amounts about 10% of the total variance over the N-Atlantic/European sector. Whether the NAO is partly forced or at least modulated by SST forcing has been investigated. The results were compared to similar ensemble integrations forced with observed SST.

FINGERPRINTS OF THE NORTH ATLANTIC OSCILLATION IN THE CLIMATE OF GALICIA (SPAIN)

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Galicia is the Spanish region placed in the Northwest of the Iberian Peninsula. Its winter climate is determined by the relative dominance of blocking or mobile cyclonic systems, which is often related to the low frequency behaviour of the North Atlantic Oscillation. The objective of this study is to find in which meteorological variable (in the surface or in the upper levels, basic or derivative) the North Atlantic Oscillation is more evident.

CLIMATE VARIABILITY IN THE NORTH ATLANTIC OCEAN USING NON-CODIFIED DATA

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The role of marine data from ships observations which are not included in the WMO system of observation is basic to study the variability of the ocean climate. Galicia, an Spanish region placed in the Northwest of the Iberian Peninsula, has one of the hughest quantities of ships crossing the Atlantic Ocean in the World. Many of these ships register meteorological data that are forgotten in their working archives. In this study we have taken as many data as possible from these archives with the aim of studying the variability of meteorological data in the North Atlantic Ocean.

CHANGES IN THE UPPER N. ATLANTIC HYDROGRAPHY AND TRANSPORTS, 1950-1994

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A number of recent hydrographic studies have shown decadal changes in the N. Atlantic ocean, possibly linked to the NAO atmospheric wind pattern. This paper presents a hydrographic analysis of XBTs from 1950-1994. Decadal timescale changes in upper N. Atlantic hydrography are found. These are consistent with previously published results by Molinari etal (1997), but more extensive in the area covered and depth range. An assessment of the heat content and water mass changes is made. The period from 1988-1994 shows changes in the Gulf stream extension which are more extreme than any previous period. By combining the XBT data with CTD and climatological data we can infer changes in Salinity and hence density structure. The circulations associated with different periods are then derived using the JEBAR inversion algorithm of Myers etal (1996) in a diagnostic finite element model of the vertically integrated vorticity equation. The results show significant decadal variability in transports in both the subtropical and subpolar gyres. These results extend the earlier 2 pentad analysis of Greatbatch etal (1991).

CHANGES IN THE INTENSITY OF THE ATMOSPHERIC SYNOPTIC VARIABILITY ASSOCIATED WITH NAO

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Intensity of the atmospheric synoptic processes is described in terms of the variances of the band-passed 4-hourly data from the NCEP/NCAR Reanalysis for the period from 1958 to 1997. Assuming that different synoptic scales can indicate different tendencies in the intensity of the synoptic and sub-synoptic processes, we study separately several ranges, which are associated with the high-frequency synoptic and sub-synoptic variability, synoptic scale transients and slow synoptic processes. These three scales indicate different spatial patterns in the mid-latitudinal North Atlantic and differences behavior in time on both decadal and interannual time scales, and show a very complicate nature which exists beyond the NAO index. The latter appears to be effective but very rough measure of the atmospheric variability on the North Atlantic mid latitudes. By using EOFs, SVD, and associated correlations, we study how the changes in the intensity of the atmospheric synoptic of different scales are linked to the SST anomalies in the mid latitudinal North-West Atlantic, temperature gradient between the North America and Atlantic Ocean and turbulent sea-air fluxes of heat and moisture in the North Atlantic. Results show complicate nature of the ocean-atmosphere interaction in the North Atlantic mid latitudes. Particularly, periods from late 1950s to early 1970s and from 1970s to 1990s indicate two different regimes of the interaction between atmospheric synoptic intensities and the ocean

TIMESCALES OF DECADAL SST-VARIABILITY IN THE NORTH ATLANTIC OCEAN

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EOF-analysis of geophysical fields is a popular tool for climatological studies. The most energetic variability of wintertime SST in the North Atlantic, a dipole-like pattern, can be found in the first EOF. However, it is questionable whether a statistical tool like the EOF-analysis can also describe physically meaningful coherence. Criticism, e.g., appear with respect to the interpretation of the Tropical dipole pattern, which seems to be caused by uncorrelated decadal SST variability north and south of the Equator.
In this paper it is investigated if the dominant EOFs of wintertime SST in the North Atlantic have their physical counterparts in the ocean too. The centers of action of the first EOF, roughly the sub-polar and western sub-tropical gyre, show variability on different time scales. More specifically, the regions south of Newfoundland as well as east of Florida show the most pronounced decadal variability ($\approx$ 13 years). In the high latitudes of the North Atlantic, however, there appears a regime shift during the early seventies which comes along with a dramatic cooling and a change in the dominant periods ($\approx$ 13 to $\approx$ 9 and 18 years) as revealed by a wavelet analysis. It will be shown that this change is accompanied by an abrupt change in the NAO-Index too. The first EOF of wintertime SST seems to combine these different kinds of variability which makes its interpretation difficult.

Decadal Air-Sea Interaction in the North Atlantic

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The 12-14 year cycle observed in the N. Atlantic SST was examined using the NCEP/NCAR reanalyses and 43 year ocean model simulation for the period 1951-1993. The evolution of the heat flux anomalies and associated SST and upper ocean heat content anomalies during the cycle are described together with atmospheric circulation changes. While the local oceanic response to the NAO forcing and the advection of SSTA along the Gulf Stream/NAC system have been suggested by Sutton and Allen (1997) and Kushnir et al. (1997), the associated changes in the heat flux and oceanic heat content in conjunction with the strength of the MOC add new understanding to the decadal cycle. A similar mode has been observed in a coupled GCM (Grotzner et al (1997)) which they attribute to the propagation of SSTA and OHCA resulting from wind driven changes in the subropical gyre circulation. Results here suggest the importance of the thermodynamic forcing.

ON THE INFLUENCE OF SINGULAR MODES ON THE ORIGIN OF THE INTERDECADAL ATMOSPHERIC VARIABILITY

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Observations and coupled climate models experiments exhibit a pronounced variability on the interdecadal and decadal timescale. For instance one interdecadal oscillation over the northern hemisphere of the coupled system ocean and atmosphere is detected with a period of about 18 years, using a 500-year integration of the Hamburg ECHAM1/LSG coupled general circulation model. The origin of the atmospheric component of this variability, in particular the changes of the storm tracks are still not well understood.
In the present paper we show that the atmospheric components of this interdecadal mode is due to their interaction with the long-term climate mean atmospheric wave field and that one branch of this interaction is manifested in the excitation of internal, atmospheric modes, in particular, in the singular modes of some linearized, steady-state atmospheric model. Our analysis based on a simple baroclinic quasi-geostrophic model, whereby the data from the 500-year integration of the ECHAM1/LSG are utilized to define the long-term mean basic state. The question of possible excitation of these singular modes by tropical or extratropical processes will also be considered.

ON THE NON-STATIONARITY OF THE NORTH ATLANTIC OSCILLATION

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The state of the dominant mode of atmospheric variability over the North Atlantic, the North Atlantic Oscillation (NAO), is commonly described in form of an index, which represents the anomalous pressure difference between Iceland and the Azores. Due to the choice of an index, the NAO-Index, it is implicitly assumed that the NAO variability is stationary with respect to the location. However, it will be shown that at least on the decadal time scale there is movement of large scale pressure anomalies which seems to be correlated with propagating as well as dipol-like behaviour of SST-Anomalies. The influence of this non-stationary character with respect to the classical NAO-Index is investigated using sea level pressure data from different analyses. The non-stationary character is also seen in the difference of the NAO-Index for different winter seasons, e.g. DJF versus JFM. It will be shown that most of the "winter" differences is due to intraseasonal changes in the Azores High which appears to be time dependent as well. Another aspect, which might go hand in hand with migratory pressure anomalies, is the non-stationarity character of the NAO-Index itself. Using wavelet analysis it will be shown, that the dominant periods of the NAO-Index has undergone several marked changes during the last 120 years.

ADVECTION OF TEMPERATURE AND HEATCONTENT ANOMALIES IN THE NORTH ATLANTIC

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Results of a numerical general circulation model of the North Atlantic with additional atmospheric boundary layer are presented. The model has been used to investigate the response of the ocean to forcing anomalies with timescales from 2 to 20 years. Periodic anomalies are applied to wind stress and to freshwater forcing in separate experiments. The results for both sets of experiments are discussed. For the different wind-variation time scales varying response in form of SST and heat content anomalies is found. For timescales longer than 6 years advective propagation of temperature and heat content anomalies similar to observations becomes visible. The advection patterns follow the major gyres in the North Atlantic. For the different timescales of the forcing variations in preferred advection paths suggest varying resonance frequencies for the paths. The advection speed of the anomalies is comparable to observed propagation speeds on the North Atlantic but exhibits differences for the different timescales of the forcing variability.

STATISTICAL ASSOCIATIONS BETWEEN THE NAO, THE SOLAR CYCLE, AND THE WESTERN BALTIC SEA ICE SEASON SINCE 1879

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The winter North Atlantic Oscillation index measures the strength of the zonal atmospheric circulation over the North Atlantic. Ice winter severity in the Western Baltic is significantly correlated to the winter NAO index in that weak (strong) ice winters tend to occur with strong (weak) westerlies. The variance sprectra of both time series show prominent quasi-cycles with periods of 2.3, 5.8, and 7.8 years. The time dependence of the spectral variance distributions is investigated through evolutional maximum entropy spectral analysis. This analysis reveals the composite character of the mean variance distributions, and shows, for instance, that the 8 years signal originates exclusively from the post-war period. An apparent association of both winter NAO index and ice winter severity with the 11 years solar acitivity cycle will also be discussed. This association consists in the preferential occurence of weak westerlies and strong ice winters in phases of low solar activity, as well as strong westerlies and weak ice winters when the phase of the solar cycle is transient downward.

BIASES IN SHORTWAVE COLUMN ABSORPTION IN THE PRESENCE OF FRACTAL CLOUDS

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We investigate the effect of cloud structure on column-absorption by water vapor. Radiative fluxes above and below horizontally inhomogeneous liquid water clouds are computed using an efficient Monte Carlo technique, the independent pixel approximation and plane-parallel theory. Cloud inhomogeneity is simulated by two related fractal models which use bounded cascades for the horizontal distribution of optical depth. The first ("clumpy") model has constant cloud top and base, hence a constant geometrical thickness but varying extinction; the second ("bumpy") model has constant extinction and cloud base, hence variable cloud top and geometrical thickness. The spectral range between 0.9 and 1.0 μm (with strong water vapor absorption and negligible cloud liquid water absorption) is selected for a detailed study not only of domain-averaged quantities but also radiation fields. Column-absorption fields are calculated as the difference between the two net fluxes above and below clouds. We show that: (1) redistribution of cloud liquid water decreases column absorption, i.e., plane-parallel absorption is larger than the independent pixel approximation one by 1–3%; (2) 3D radiative effects enhance column absorption by about 0.6% for the clumpy model and 2% for the bumpy model, i.e., Monte Carlo absorption is larger than independent pixel approximation absorption; this effect is most pronounced for the bumpy cloud model at solar zenith angle $\approx 45°$; (3) plane-parallel absorption is larger than 3D Monte Carlo absorption for high solar elevations and nearly equal to it for low solar elevations. Thus, for extended clouds of thickness 1–2 km or less, in an important water vapor absorption band (0.94 μm), we do not find a significant enhancement of cloud absorption due to horizontal inhomogeneity.

SENSITIVITY OF THE NORTHERN HEMISPHERE ATMOSPHERIC CIRCULATION TO NORTH ATLANTIC SSTs IN THE ARPEGE AGCM

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A set of four extreme SST anomaly patterns in the North Atlantic Ocean has been derived from observed SSTs (GISST 2.2 dataset) and used as lower boundary conditions in the ARPEGE Climate AGCM at T42 resolution. Those SST patterns mainly differ in which sign was imposed to the respective SST anomalies on the western and eastern sides of Greenland. Twenty ensemble runs have been performed with each SST configuration for the three winter months. The model response has first been analyzed in terms of changes in the heat fluxes and temperature at the surface, and then in terms of modifications of the general tropospheric circulation over the Northern Hemisphere. A particular focus has been laid on the changes in the storm track and transient eddy activity, in conjunction with modulations of the North Atlantic Oscillation. The most significant differences appear in the forcing area, but also over Europe and to a lesser extent in the North Pacific. In particular, the simulated North Atlantic storm activity turned out to be enhanced and extended further east, over Western Europe, when the Labrador Sea is colder than usual.

An Oceanic memory of winter conditions: does it feedback to determine the winter NAO state?

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The North Atlantic Oscillation (NAO) is characterized by organized shifts in intensities and positions of the Iceland low pressure center and Azores high pressure ridge, a SLP seesaw most well organized in winter. The winter NAO history exhibits decadal trends and persistent high and low intensity states. This is somewhat remarkable: the non-winter atmospheric state does not show patterns that are correlated with the adjacent winter state, yet successive winters tend towards correlation, an interannual memory of the preceding winter state in spite of this seasonal loss of memory. Evidence is presented for the participation of a memory mechanism in the upper ocean in the decadal NAO variability. At mid- and high-latitudes there is a warm - to - cold water transformation pipeline that links the western subtropical gyre to the eastern and northern subpolar gyre and conveys heat to mid and high latitudes where it is liberated to the atmosphere. That pipeline reflects the central role of meridional heat advection by the ocean in the regional climatic heat budget. Along this pipeline winter SST anomalies slowly drift. These are heat content anomalies of the winter convecting "Mode Waters" that are the agent of that transformation. The Mode Waters sequester a "memory" of the preceding winters' conditions, for recurrent winter exposure downstream along the transformation pipeline. Is this memory mechanism feeding back to determine the winter atmospheric state?

VARIABILITY OF THE NORTH ATLANTIC OSCILLATION SINCE 1881

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North Atlantic Oscillation: decadal variability in ocean and atmosphere e-mail: maechel@uni-bonn.de, fax: 0049 228 735188

Based on generated time series of the central pressure, latitudinal and longitudinal position of the Iceland Low (IL) and Azores High (AH), the behaviour of these atmospheric centres of action is examined with regard to the intra- and interannual variations, persistence of anomalies, linear trends and interactions. The critical analysis of these time series as well as those of the pressure gradients between the cores of AH and IL (the proposed index of the North Atlantic Oscillation) suggest that the existing non-periodic fluctuations of the surface atmospheric circulation on the time scale of one or more decades suppress the long-term changes. These fluctuations are similar to the 'internal' variations of the climate system, recognized in the climate simulations of coupled ocean-atmosphere models. Using the anomalies of the time series mentioned above, it can be shown that these are practicable tools for the detection of characteristic spatial anomaly patterns in different climate variables above the North Atlantic and surrounding land areas. 'Strong' NAO in winter leads to a warming above northern and central Europe as well as to the development of depole-like anomaly patterns in the wind speed, sea-surface temperature, surface and tropospheric temperature and other variables obove the western and eastern North Atlantic. The composite analysis for 'weak' NAO reveals inverse patterns.

NORTHERN ATLANTIC TEMPERATURE AND PRESSURE PATTERNS RELATED TO HEMISPHERIC MEAN TEMPERATURE VARIATIONS

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Time series of Northern Atlantic near-surface atmospheric temperature and pressure patterns, and also SST in the Smed squares are analysed in relation to the hemispherical temperature characteristics at the decadal time-scales. Method of 'slices' is applied (Mika, 1990) to quantify linear connections between the NA grid-point values, as dependent variables, and hemispherical mean air temperature plus the air temperature contrast between continents and oceans of the Northern Hemi-sphere, as independent variables. According to this methodology, the large-scale and local series are divided into sub-periods of uniform length between 5 and 25 years to randomise local and hemispherical data inhomogeneities. Temperature fields North from 30o N are characterised by large positive relative sensitivity (regression coefficient) patters in the region of Greenland. Summer half-year differences between sensitivities of SST and air-temperature coefficients to the hemispherical temperature variations are not high. The winter half-year sensitivity patterns of the air-temperature, however, are much stronger near the Smed-squares than those derived from SST. The main feature of the Atlantic-European sea-level pressure is the weakened zonality in the winter half-year parallel to the hemispheric warming. Intensity of North-Atlantic Oscillation exhibits positive connection to the continent-ocean temperature contrast at the decadal time scales.

THE NORTH ATLANTIC OSCILLATION IN ANALYSIS AND MODEL DATA SETS

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The spatial and temporal structure of the North Atlantic Oscillation is examined in analysis data from the Deutscher Wetterdienst and several model data sets from the coupled climate model ECHAM-3 / LSG in Hamburg and uncoupled ECHAM-3 simulations. Time-series of latitudinal position and central pressure of the Islandic Low and the Azore's High are determined from each data set. The index of the North Atlantic Oscillation is then built by the first principal component of these four time-series. On the base of annual means we find index values within minus and plus two and a strong interannual variability. Only the low pass filtered time series of the NAO index show a certain periodicity on time-scales of about fifty years. The comparison of the observed and simulated North Atlantic Oszillation leads to rather different results depending on the external forcings e.g. greenhouse gases and/or sea surface temperatures. The ECHAM-3 / LSG seems to reproduce the North Atlantic Oscillation in an excellent way on the interdecadal timescales although we have to keep in mind that only 2-3 realisations of the long term vascillation are observed.

Coupled variability in the slopewater inshore of the Gulf Stream

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Two hydrographic data sets at 55W and 50W are used to investigate the mean features and variability of the slopewater south of Newfoundland, inshore of the Gulf Stream. It is found that the entire water column---including the Labrador Current, slopewater jet, Labrador Sea water and Norwegian-Greenland overflow water---varies in coupled fashion on interannual timescales. The upper-layer slopewater front/jet is discussed in detail. Both the lateral position and strength of the front vary on long time scales. An EOF analysis at 55W reveals that the variability of the slopewater jet is coupled to that of the deeper water masses, including both the Labrador Sea water and Denmark Strait overflow water. The 50W data reveal that the main branch of the Labrador Current also varies in phase with the slopewater jet. The general picture which emerges is that the entire upper-layer slope water circulation spins up and down on interannual timescales, coincident with strengthening/weakening of the overflow component of the deep western boundary current. The relationship of this variability to the NAO is discussed.

THE INFLUENCE OF THE STRATOSPHERIC CIRCULATION ON THE TIME STRUCTURE OF THE NORTH-ATLANTIC-OSCILLATION

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During the winter months there is a close relationship between the strength of the stratospheric polar vortex and the phase of a tropospheric wave-like pattern, which includes the North-Atlantic Oscillation (NAO). This main mode of the coupled circulation system troposphere/stratosphere evolves from the mean flow - wave interaction between tropospheric planetary waves and the stratospheric west winds. There is a growing body of evidence indicating that this main coupled mode has effect not only on the intraseasonal and interannual but also on the interdecadal time scale. The observed trends of the northern hemispheric winter circulation over the last 40 years are an indication for this interdecadal coupled behaviour of stratospheric and tropospheric circulation. The trends are characterized in the stratosphere by an intensification of the cyclonic polar vortex and in the troposphere by a strengthening of the westerlies over the North Atlantic.
The active influence of the stratospheric circulation on the amplitude and the interdecadal behaviour of the NAO will be shown using both observations and experiments with a coupled atmosphere-ocean model.

DECADAL-SCALE VARIABILITY OF THE COUPLED OCEAN ATMOSPHERE SYSTEM IN THE NORTH ATLANTIC OCEAN: MANIFESTATION AND MECHANISM

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The goal of this talk is to discuss the manifestation of the decadal-scale variability in the North Atlantic Ocean and possible mechanism generating the decadal coupled mode. We used the surface historical data sets for 1948 to 1992, such as COADS and its Russian analog and subsurface North Atlantic hydrographic data for 1969 to 1992. We confirm the coupled nature of the decadal mode in the North Atlantic. It manifests itself as a coherent high-amplitude variability of the surface and subsurface fields and associated decadal change of the NAO index. The positive correlation of sea surface pressure anomalies with sea surface temperature anomalies resulting in decadal-scale change of the Ekman meridional transport in the North tropical Atlantic is the crucial element of the positive feedback in the coupled system generating the decadal coupled mode. We confirm this result using the box model of the coupled ocean-atmosphere.

DECADAL CHANGE OF THE LARGE-SCALE ATMOSPHERIC CIRCULATION OVER THE NORTH ATLANTIC EUROPEAN REGION IN JANUARY OF THE 80's

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It is known that over Europe the ozone trend in January of the 80s is almost twice that of the zonal mean. It was shown that this strong ozone decrease over Central Europe is caused by a decadal change in the large-scale circulation over the North Atlantic European region.

The aim of this paper is to study the dynamics in boreal January of the 80's on the basis of NCEP-data set in connection with a simple model. It is shown that an enhanced Rossby wave track exist in the 80s over the North Atlantic European region which belongs primarily to a wave 3 structure forced in the boundary layer. The connection of this change with an enhanced NAO will be discussed.

UPPER OCEAN VARIABILITY RELATED TO NAO IN THE NORTH ATLANTIC SUBARCTIC GYRE IN RECENT YEARS

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50-year long time series of upper ocean data in the subarctic gyre suggest the presence of pluriannual signals propagating clockwise around the North Atlantic subarctic gyre. In the Labrador Sea, they are closely associated with changes in ice cover and correspond to changes of the cold watermasses of polar or arctic origin. In the northeastern Atlantic, they correspond to changes in the modified North Atlantic water, mostly along average T-S characteristics. Unfortunately, these time series are spatially too coarse to provide a dynamically coherent vision of what is happening and how the two phenomenon are related. A regularly sampled ship-line between Newfoundland and Iceland provides new information on the variability in this region in particular since 1993. The modes of variability of upper ocean temperature from XBTs are compared with surface salinity changes measured by a thermosalinometer, near surface currents from altimetric measurements and winds from ECMWF. They all suggest changes happening during late 1995 and early 1996 in the northern part of the section from cold and fresh toward warmer and saltier waters with an aossciated change in NAO from high to low index. The variability of the water masses close to the Labrador current is not so well sampled by the section and does not seem highly correlated with the changes further to the north-east.

VARIATIONS OF SEA ICE EXTENT IN THE NORTHERN ATLANTIC ON DECADAL TIME SCALE AND CONNECTION WITH ATMOSPHERIC CIRCULATION.

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Formation of sea ice seems to be a key process in the interplay between the atmosphere and ocean in the Arctic region. Modelling studies show, that the coverage of the sea by ice represent a thermal forcing of the atmosphere by preventing the convective heat fluxes from the ocean to the atmosphere. On the other hand, the atmosphere may influence the formation of sea ice by fresh water input through precipitation to the surface layer and by advection and convergence of fresh water masses.

In the present study, these processes are studied during the period 1960-1995 by utilising precipitation and wind stress data from NCEP/NCAR dataset and ice data from the Walsh dataset. Key areas for fresh water input and Ekman convergence will be identified and associated time indices constructed. Comparison with sea-ice indices and the atmospheric North Atlantic Oscillation index will be performed. Finally, the role of the various mechanisms in the observed decadal variability will be discussed. Recent AGCM experiments will perturbed sea ice extent will also be discussed in this context.

ABOUT THE THERMOCLINE VENTILATION: SPIN-UP AND SPIN-DOWN

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The thermocline variability under an instantaneous variation of the Ekman pumping is studied, using a two and a half layer geostrophic model. Since the second layer is allowed to subduct, the model is able to represent the ventilated zone and the shadow zone. It is found that, north and south of the subduction line, the thermocline depth strongly varies, in contrast to previous results gained with simpler models (e.g. Liu, 1993). These variations are mainly due to the propagation of a Rossby baroclinic wave (first mode) across the basin. South of the subduction line, dynamics depend on complex non linear interactions between advection, baroclinic Rossby waves (first and second modes). Noticeable differences between the shadow zone and the ventilated zone are analysed.

ON THE MECHANISM OF NORTH ATLANTIC DECADAL VARIABILITY

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North-Atlantic decadal climate variability is studied with a coupled atmosphere/ocean/sea-ice model (ECBILT). The covariability between the atmosphere and ocean is explored by performing a Singular Value Decomposition (SVD) of boreal winter SST anomalies and 800 hPa geopotential height anomalies. The second mode shows a peak in both spectra at a timescale of about 16-18 years. The geopotential height pattern is the model's equivalent of the North Atlantic Oscillation (NAO) pattern, the SST anomaly pattern is a north-south oriented dipole. Additional experiments have revealed that the decadal oscillation in ECBILT is basically an oscillation in the subsurface of the ocean. The oscillation is excited by anomalies in the atmospheric NAO pattern, both through anomalous surface heat fluxes and anomalous Ekman transports. The atmospheric response to the SST anomaly enhances the oscillation and slightly modifies it, but is not essential. The atmospheric response consists of a local surface temperature adjustment to the SST anomaly and a slight change in the probability of occurrence of anomalies in the atmospheric NAO regime. An important element in the physical mechanism of the oscillation is the geostrophic response of the ocean circulation to the forced temperature anomalies creating surface salinity anomalies through anomalous horizontal advection.

Decadal variability on the Northwest European Shelf

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The seasonal cycles of sea surface temperature and other parameters at eight sites on the Northwest European shelf show an interannual variability in the range of years to decades for the years 1970-1995. Statistical methods like spectral analysis or phase diagrams prove that only a few frequency peaks behind the annual cycle are of real significance. Most prominent signals for temperature and salinity in the southern North Sea are at periods around 8 and 17 between different states of equilibrium.

Explanations for the decadal variability can be given by the intrinsic time scales of the internal shelf dynamics as well as by external periods. A spectral analysis of calculated mass fluxes through the Shetland-Orkneys section shows that there are hardly significant periods behind the seasonal cycle. This does not suggest a major advective influence from the Atlantic Ocean. The most probable external source of decadal variability on the Northwest European shelf is the atmosphere. The hypothesis means that no phase shift can be expected between corresponding signals of time series at different North Sea sites as it is indeed observed.

WIND DRIVEN VARIABILITY OF THE NORTH ATLANTIC MERIDIONAL OVERTURNING CELL IN THE ECHAM1/LSG COUPLED OCEAN ATMOSPHERE MODEL

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The variability of the meridional overturning circulation (MOC) in the North Atlantic ocean is analyzed in a long term simulation with the ECHAM1/LSG coupled ocean atmosphere model. The main mode of variability represents a modulation of the MOC and its frequency spectrum decays inversely to the frequency down to centennial time scale. The second mode describes a shift in the sinking region and has a white spectrum. On the time scales ranging from interannual to decadal, it is found that the main source of MOC variability is mechanical. It is linked to the white noise Ekman pumping in the middle and high latitudes that is associated with the dominant mode of variability of the model atmosphere.The freshwater flux plays no apparent role on these time scales and the surface heat flux tends to damp the fluctuations, but they may well play a more active role at longer time scale.

LONG -TERM CHANGES OF THE MEDITERRANEAN WATERS IN THE NORTH EAST ATLANTIC AND ASSOCIATED CHANGES OF THE THERMOHALINE CIRCULATION

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Long-term changes of T-S properties of Mediterranean outflow water in the Northeast Atlantic over the time period 1970-80 are considered. The outflow is formed by the intermediate and deep waters of the Mediterranean Sea. The latter, being the product of the convection processes, are apparently linked to the atmospheric conditions over the sea, which in their turn are characterised by the NAO index. It was established that in the 70s the outflow water became warmer and saltier. These tendencies were characterised by significant linear trends of 0.04 °C/year and 0.01psu/year, respectively. It was also found that at the same time, the above lying thermocline waters experienced changes of the opposite sign and approximately the same magnitude. An attempt to find the associated changes of the thermohaline circulation in the Northeast Atlantic (specifically the North Atlantic Current) has been undertaken.

NORTH ATLANTIC DECADAL VARIABILITY IN A 130-YEAR SIMULATION OF THE CURRENT CLIMATE WITH A GLOBAL COUPLED GCM

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In this work, we describe the (quasi-)decadal variability found in the thermohaline structure and circulation in the North Atlantic region from a 130-year climate simulation with the ARPEGE-OASIS-OPAICE coupled general circulation model (GCM). Emphasis is placed upon the thermohaline behaviour in the upper ocean and main thermocline of the subpolar gyre, where the strongest variability occurs. A rich structure of oceanic variability is depicted and related to aspects of air-sea-ice-ocean interactions at high-latitudes. In particular, a variability pattern with an 8-year dominant timescale emerges and is clearly significant compared to the red-noise background. Multi-Channel Singular Spectrum Analysis (MC-SSA) of upper ocean temperature and salinity fields shows vertically coherent oscillations slowly propagating along the North Atlantic Drift. This quasi-decadal mode has a dipole-like structure and appears to be correlated with changes in Labrador sea-ice concentration and anomalous Ekman pumping associated with changes in the wind stress curl. This mode of variability bears some resemblance to the mode found in a recent observational study of North Atlantic hydrographic data (Reverdin et al. JGR 1997). Furthermore, the simulated Arctic sea-ice variability spectrum is shown to be strong at various timescales and geographical locations, in contrast with other coupled GCMs simulations.

DETECTING POTENTIAL ATMOSPHERIC FEEDBACKS OF DECADAL NORTH ATLANTIC CLIMATE VARIABILITY IN AN ENSEMBLE OF MULTI-DECADAL AGCM SIMULATIONS

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Ocean-atmosphere interactions involving the North Atlantic Oscillation (NAO) are believed to be partly responsible for decadal climate fluctuations in the North Atlantic/European sector. The timescale of a suggested coupled mode may be set by the subtropical ocean gyre circulation in conjunction with changes of the atmospheric circulation. These atmospheric changes, in turn, are supposed to be partly forced by variations of the North Atlantic sea surface temperatures (SSTs). The sensitivity of the atmosphere to low-frequency North Atlantic SST changes, however, remains controversial. In this study we use an ensemble of six 45-year integrations of the Hadley Centre atmospheric model (HADAM1) to assess this question. The model was forced by the Hadley Centre's observed sea-ice and sea surface temperature data set (GISST) for the period 1949-93 and the six integrations were initialised with different atmospheric states. We derive a multivariate signal-to-noise maximising method to consistently estimate a significant response of the atmosphere model to the oceanic forcing.

Changes in the NW Mediterranen Sea Circulation and their possible connection to the North Atlantic Oscillation

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The North Atlantic Oscillation appears to exert a strong influence on the Mediterranean meteo-climatic conditions which, in turn, are reflected in the underlying driven ocean circulation. In order to test a possible link between the interannual variability of the water mass circulation and the NAO behaviour, the water transport through the Corsica Channel has been examined. This is a good indicator of how the NW Mediterranean Sea circulation responds to seasonal changes affecting the overlying meteorology. The collection of data started in 1985 and still ongoing. This data set is the most complete and long-term one of this kind in the Mediterranean Sea. The oceanographic evidence shows that significant interannual changes appear essentially during the colder season with a substantial decadal decrease which leads in 1995 to a value about 70% less than in 1986 and then a suddenly strong reversal in 1996 occurs. Since 1980, a NAO index shows an unprecedented persistence of the positive phase and the highest values occur during this period. In 1996, this trend is breacked and the index exhibits the lowest value in this century. Despite of the short length of the oceanographic time series, the same but opposite superimposed decadal tendence and the same sharp reversal at the end seem to suggest that a tight mechanism operates between NAO and the water mass circulation at interannual scales.

RESPONSE OF AN NORTH ATLANTIC OCEAN MODEL TO NAO-LIKE FORCING

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The North Atlantic sector shows significant variability from interannual up to decadal and longer time scales. Investigations of historical data sets reveal identifiable patterns and covariation between the atmosphere and ocean over the Atlantic. However, the mechanisms and interactions between the atmosphere and the ocean which generate these patterns are not well understood. We will present results from an ocean only model forced by NAO-like variability in the wind and air-sea flux fields.
The ocean model, which is coupled to an atmospheric boundary layer model, is forced by adding observed NAO wind anomalies to the seasonal forcing with a monochromatic period of 2, 6, 12 and 20 years. The model SST response shows similar structures when compared to the observations. The strength of the response increases slightly in amplitude and significantly in area for longer periods. The upper ocean heat content changes are dominated by variable ocean advection as a consequence of the altered surface wind stress. Local air sea fluxes are only of secondary importance outside of the tropical region. The heat content anomalies show a propagation form the subtropical to the subpolar gyre in agreement with the observations.
The implications for the role of the ocean in perturbing the atmosphere will be discussed.

DO CHANGES IN THE NAO EXPLAIN TRENDS IN SWISS WINTERTIME PRECIPITATION?

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Wintertime (DJF) precipitation in Switzerland has increased during the periods 1961-1990 and 1901-1990 by up to 30%. Here we attempt to relate these trends to changes in the large-scale atmospheric circulation, using singular value decomposition (SVD).
For the winters 1961-1990, the North Atlantic Oscillation Index (NAOI) has a positive trend. Yet it can not explain the precipitation trend, since NAOI and Swiss precipitation are almost uncorrelated on a monthly time scale. However, 80% of the precipitation trend are attributable to changes in SLP by means of the leading mode of a SVD between monthly SLP and Swiss precipitation. The trends of both the NAOI and the SVD mode represent an increasingly westerly flow towards Central Europe, but only the latter filters out the component of the SLP trend which is actually linked to Swiss precipitation.
These results indicate that the commonly used NAOI might not be optimal to describe large-scale influences on parts of the central European sector. Our SVD analysis shows that alternative SLP anomalies exist whose time series correlate well with precipitation but only poorly with the NAOI. Further analysis for the winters 1901-1990 also suggests that temperature trends during the centennial period might be relevant for explaining the observed precipitation trends.

NAO - RELATED CHANGES IN THE SEA LEVEL PRESSURE FIELDS OVER THE NORTH ATLANTIC

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Based on the National Centers for Environmental Prediction (NCEP) data set analysis of the climatic changes of winter mean anomalies of sea level pressure (SLP) and its intramonthly root mean square deviations (RMSD) is carried out. Climatic changes are considered in terms of linear trends, low-pass filtered anomalies and decadally averaged anomalies. It is demonstrated that linear trends of winter RMSD anomalies are in a good agreement with SLP trends attributed to the periods of decrease (icrease) of NAO index. Analysis of the detrended and low-pass filtered anomalies of winter SLP revealed both propagating and standing patterns. The standing patterns have a period of about 8 years. There is no good agreement with related changes of RMSD. On the contrary, we defined the periods with high (low) values of NAO index, which accompanied by negative (positive) anomalies of RMSD. Decadally averaged RMSD anomalies are not linked to the North Atlantic storm track. Spatial distribution of both winter SLP and RMSD anomalies demonstrates meridional dipole-like patterns. For the period 1981-1990 which is characterized by the high value of NAO index, the negative anomalies of RMSD over the most of the North Atlantic are observed.

OA4 Circulation variability at mesoscale

Convener: Millot, C.
Co-Convener: Treguier, A.M.

INTERACTIONS OF OCEAN EDDIES WITH BOTTOM TOPOGRAPHY

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Interactions of ocean eddies with bottom topography are important in generating mean abyssal currents, although the causal mechanisms are poorly understood.
We present results from a series of idealised numerical experiments in which an ensemble of eddies interact with a simple Gaussian bump, and generate a mean circulation. We find that total energy is approximately conserved, whereas potential enstrophy is dissipated, relative to values predicted by spin down to a state of rest.
Based on these results we attempt to parameterise the eddy-topography interactions in terms of an eddy-induced transport velocity (Gent et al., JPO '95). By assuming potential enstrophy is dissipated, while conserving the total energy and volume of fluid between isopycnal layers, we find that the eddy-induced transport velocity is related to gradients in *both* the slope of the isopycnals *and* the potential vorticity. This is contrary to the Gent and McWilliams eddy parameterisation which relates eddy-induced transport velocity purely to the slope of the isopycnals.

CHARACTERISTICS OF THE CIRCULATION IN THE BAY OF CASSIS

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The circulation in the bay of Cassis (Gulf of Lions) is influenced by the easterlies or northwesterlies, especially the Mistral that generates there an intense upwelling. It is also influenced by the general circulation, flowing along the continental slope and meandering, mainly in autumn-winter, so that some mesoscale phenomena can make incursions into the bay, especially through a canyon. From May 1995 to May 1996, current and temperature data were collected, while a fortnightly hydrological survey was conducted, in both the coastal and offshore areas.
Near the head of the canyon, maximum currents of 35-40 cm/s are frequently observed in autumn-winter, during several hours/days, over upper tens of metres and over the whole ~200 m water column when quasi homogeneous. At this place and during this season, the velocities over a few tens of metres close to the bottom are sometimes higher than above. This is due to an acceleration by the canyon of the shoreward currents that are thus strongly constrained by the topography. In summer, the maxima are 10-20 cm/s within the mixed-layer. The currents near the head of the canyon are generally not wind-induced and are probably forced by the mesoscale phenomena associated with the general circulation. Elsewhere in the bay, at depths shallower than ~100 m, the maxima reach frequently 30-55 cm/s (resp. 20-40 cm/s) in autumn-winter (resp. in spring-summer). There, two simple wind-induced circulation schemes are evidenced with an EOF analysis. Nevertheless, the mesoscale variability that is not wind-related is not negligeable. Hence, the circulation at depths shallower than ~100 m is complex and results from a combined effect of both the wind and the general circulation.

DYNAMIC ACOUSTIC TOMOGRAPHY OF AN INTRATHERMOCLINE EDDY IN THE WESTERN MEDITERRANEAN

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The research is aimed at studying the possibilities of remote acoustic monitoring of mezoscale intrathermocline eddies (IE). Applicability and performance of conventional and dynamic approaches to acoustic tomography are compared. The research is based on a detailed survey of cold and low saline IE lens observed in the Western Mediterranean sea in July 1994. Using the data of acoustic and hydrographic measurements we study thermohaline, dynamic and kinematic structure of the eddy. The potential and kinetic energies associated with the eddy are estimated. Possible models of generation, evolution and dissipation of such inhomogeneities are discussed.

The results are generalized to study the influence of mezo- and sub-mezoscale IE on heat, salt and mass interchange in intermediate water layers in oceans and interior seas. Contribution of eddies to climatic variability of thermohydrodynamic fields is evaluated using hydrographic data of IO RAS, VNIIGMI MCD (Obninsk, Russia) and NODC.

DESCRIPTION AND HISTORY OF THREE AGULHAS RINGS INTERSECTED BY WOCE HYDROGRAPHIC LINES A13 AND A14

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Three Agulhas eddies of very different core characteristics were intersected by the WOCE hydrographic lines A13 (at 34°30S, 11°E) and A14 (at 31°30S, 9°W and 26°S, 9°W) in February 1995. The eddy observed near the formation region along A13 had a core temperature of 11.6°C revealing important winter cooling in the retroflection region, whilst one of those observed along A14 had a core temperature of 17.1°C, hardly lower than that of the Subtropical Mode Water of the South Indian Ocean, an indication that it escaped the retroflection region without having suffered the effects of winter. These two extreme examples show that ventilation of the South Atlantic by Agulhas rings affects the density range $25.55 \le \sigma_\theta \le 26.75$. The eddy trajectories determined from the sea surface height anomalies of the TOPEX POSEIDON altimeter confirm that the A13 eddy was formed at the beginning of the austral fall, and spent the whole following winter south of 42°S. Comparison with the weakly altered eddy gives a heat loss of $8.7\ 10^9\ J\ m^{-2}$, and a rough equivalent winter surface heat flux of $600\ Wm^{-2}$, more than twice the climatologic values. The two eddies observed on A14 are also very different, with core temperatures of 17.1°C and 13.6°C. Surprisingly, both could be traced back to the same initial eddy, which was subdivided on encountering the Erica Seamount at the eastern tip of the Agulhas Ridge. The northern part moved directly to the South Atlantic while the southern one stalled in the retroflection region during the winter.

Wind driven dynamics of river plume in the Mediterranean sea

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December 23, 1997

Variability of the 3D dynamics of Mediterranean river plumes induced by river discharge rate and wind strength is investigated from numerical modelling. The 3D model, involving TVD scheme for density front capturing and non isotropic turbulence model is calibrated and validated by field measurements performed in the case of Rhône and Ebro sites.

SPOT and LANDSAT data are used to analyze the high variability of the induced circulation in the region of freshwater influence and to estimate concentrations of Total Suspended Matter.

INSTABILITIES OF AN INTERMEDIATE WATER CURRENT

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Experiments have been conducted on the "Coriolis" rotating platform to study the stability conditions for a current of intermediate water. The flow is introduced in a two-layer system along the vertical sidewall of the tank. The flow rate at the injector level and the free surface height are constant. With the geostrophic assumption, such a current is characterized by three aspect ratios, the Rossby or Froude number and the Ekman number. We observe five typical flow regimes: (1) a stable current for large Rossby and Ekman numbers defined at the injector level; a significant evolution of the current when these numbers decrease with (2) a serie of cyclonic vortices attached to the wall with an upstream stable current, (3) an anticyclonic instability, (4) dipoles shed from the current and (5) generation of anticyclonic lenses of intermediate water, alike "Meddies", for the smallest values of Rossby and Ekman numbers. A Shallow-Water of an intermediate water flow is developped and fits very well with the experiments when the current is unstable. Energy transformations show that the nature of the instabilities is mixed namely both barotropic and baroclinic. In fact, the kind of phenomenon which appears depends on the relative importance between the barotropic instability and the baroclinic instability. As regards a stable current, it is geostrophic. Its downstream widening can be explained by the Ekman transport at the interfaces and Kelvin-Helmholtz instabilities.

Mesoscale and Synoptic Near-Bottom Water Dynamics at test areas in the Clarion - Clipperton province of the Northeast Tropical Pacific

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Mesoscale and synoptic current variability and estimates of mean and fluctuating kinetic energy (MKE and FKE) in the near-bottom layer are considered on the basis of twelve 3 to 13 months time-series from 9 subsurface moorings within three test areas. Data were collected in frameworks of international projects during 1991-1995. Quite a stable long-term direction of benthic currents is found for all sites and, in most cases, the topographic control of the direction is revealed. Mesoscale and synoptic energy spectra were analyzed. MKE and FKE estimates showed that MKE over observational periods were low (0.1 to 1.5 cm2s2) and FKE were mostly about 4-5 times higher than MKE. MKE and FKE determined for different seasons and months as well as "time-series" of those constructed from several days averaged data allowed us to show features of time variability of the energy of different scales. The comparison of evaluating parameters for different moorings and levels above the bottom contributes in parametrization of synoptic and mesoscale processes in high resolution circulation models.

SHORT-PERIOD VARIABILITY OF THE LUDERITZ UPWELLING CELL

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The system of cold local upwelling cells (Cunene, Namibia, Walvis Bay, Luderitz and Namaqua) of the Benguela upwelling region (15-32S) has been identified and investigated by analysis of daily satellite images (AVHRR) of sea surface temperature (SST) in January-February 1986 and April-June 1988. The Luderitz upwelling cell 100-400km long, 50-100km wide, having 4-8C SST
contrast with oceanic waters, has been found to be the most frequent and intense. Day by day variability of its position (northern and southern limits), length, width, SST, SST contrast with surrounding and oceanic waters and SST gradients has been investigated. The analysis showed irregular pulses of 2-10 days with large variations of cell characteristics, related with the South Atlantic Anticyclone intensity.

EDDY-DRIVEN BAROTROPIC TRANSPORT CONTROL BY BOTTOM FRICTION: THEORETICAL AND NUMERICAL RESULTS

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The generation of localized, but large-scale, topography-related anomalies in the wind-driven circulation is revisited analytically and numerically. The novel effect argued theoretically is that barotropic transport near topography can come under the direct control of the eddy field and bottom friction. Such control emerges roughly in the event that the topography forms closed f/h contours. We examine the mean flow around the Zapiola Drift, a large scale depositional feature found in the South Atlantic, in light of the theory. In particular, the 80 Sv transport observed recently around this topographic feature can be rationalized. The basic elements in the theory controlling the circulation are eddy driving and bottom drag. These dynamics are supported by numerical experiments with a multi-layer quasigeostrophic model. Numerical simulations using an eddy-resolving sigma coordinate primitive equation model (SPEM) outfitted to the South Atlantic are also described. This model, under climatological monthly mean surface forcing, reproduces the Zapiola Anticyclone. The basic dynamical features of the theory are supported by this primitive equation model, as demonstrated by experiments with varying lateral and bottom friction. Interestingly, other topography-related features of the simulated Southern Ocean circulation also agree with the theoretical predictions, although comparable observational verification is lacking.

THE PATHWAYS AND KINEMATICS OF MEDDIES IN THE IBERIAN BASIN

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Between May 1993 and March 1994, 44 RAFOS floats were deployed sequentially in the Mediterranean Undercurrent south of Portugal as part of A Mediterranean Undercurrent Seeding Experiment (AMUSE). Ballasted for the lower core of the Undercurrent (1100-1200 dbars), the floats were tracked acoustically for up to 11 months.
These float tracks revealed the formation of nine meddies along the Portuguese continental slope, and their subsequent translation through the Iberian Basin. These observations have been combined with float observations from two other meddy studies to describe the pathways and kinematics of newly formed meddies.
Some meddies that formed near Cape St. Vincent drifted rapidly northward along the continental slope for several hundred kilometers before drifting into the interior. One of these left the boundary near 38N, but continued drifting northwestward, reaching a maximum latitude of 39N before gradually turning toward the southwest. After 11 months, the net displacement of this meddy was slightly north of west (not southwestward). This suggests that the age of meddies in the Canary Basin, which have been estimated assuming a southwestward drift from Cape St. Vincent, may have been underestimated.

BAROCLINIC INSTABILITY OF A MERIDIONAL CURRENT

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Recent observations in the intergyre region of the northeastern Atlantic Ocean showed low frequency mesoscale variability. SOFAR floats were thus advected for several years in zonal jets, both westwards and eastwards.The linear theory shows that baroclinic instability of the large scale currents, which are quasi-meridional and weakly sheared in the vertical, can drive such motions. A quasi-geostrophic, 3 layer model is used to analyze the non linear regime of this instability, in an idealized configuration. The characteristics of the unstable modes depend essentially on the relative intensity of the mean curent vertical shear, which is the source for the instability, and the β effect, which is the stabilizing parameter. Taking into account the planetary vorticity gradient prevents the barotropic cascade towards large scales from occuring, driving to a statistical equilibrium with zonal patterns of current. We focus on the ability of this process to contribute to the zonal transport of properties, and to excite long Rossby waves. This mechanism may be important in the spreading of the mediterranean salt tongue to the West, together with the large scale advection and the transport by meddies. Basin scale circulation models generally do not well represent this process because the dynamics of the eastern basin is not very well simulated, and because the numerical stability implies the use of large diffusion coefficients, which prevent instabilities from growing.

FLOAT DISPERSION AND THE CLIMATOLOGICAL POTENTIAL VORTICITY DISTRIBUTION

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Potential vorticity is defined as $Q = -\frac{f+\zeta}{\rho}\frac{\partial \rho}{\partial z}$ where f is planetary vorticity, ζ is relative vorticity, ρ is density and z is the vertical coordinate. In a steady, adiabatic flow, Q is materially conserved, and water particles are constrained to follow isolines of Q. The extent to which this regime applies in the North Atlantic is tested by comparing float trajectories with the large scale climatological distribution of Q, approximated by $-\frac{f}{\rho}\frac{\partial \rho}{\partial z}$ where it is assumed that $\zeta << f$.
In the interior the mean angle between float trajectories longer than two years and Q isolines is less than 9°, suggesting an adiabatic regime where Q is nearly conserved. In the western boundary current larger angles reflect a different dynamical regime where water particles cross isolines of Q, possibly as a result of eddy mixing. The root mean square change in Q for floats in the interior saturates over timescales of about 50 days near the equator and 100 days at 40°N, also suggesting near conservation of Q. After the initial period of adjustment, dispersion is restricted to the direction along isolines of Q.
We speculate that this preferential eddy dispersion along isolines of Q will control the distribution of tracers in regions where the background flow is weak.

INTERLEAVING IN THE EQUATORIAL PACIFIC

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Temperature and salinity observations in the Western Equatorial Pacific have shown interleaving layers with vertical scales of around 50 m which extend laterally for 100 km or more. These features have profound implications for mixing and transport but their origin is unclear, since mean conditions are often favourable for both double-diffusive interleaving and inertial instability. We present the results of a new linear analysis on the beta-plane which allows us to consider both processes simultaneously.
Under certain conditions the layers can reach an equilibrium at finite amplitude, but if the salinity front is sufficiently strong the density structure can become unstable and convection sets in. The behaviour of the layers in this nonlinear regime is investigated using a non-hydrostatic model with a simple parameterization for the double-diffusive fluxes.

A FINITE ELEMENT MODEL FOR THE BAROTROPIC VORTICITY CONSERVATION EQUATION: THE CANARY ISLANDS

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A finite element model code has been developed to simulate the barotropic vorticity conservation equation. The main purpose of this model is to resolve vortex shedding from islands, where finite elements have been chosen as they adapt to any contour line. In the vicinity of islands, the appearance of vortices in nature are important as they are associated with upwelling/downwelling, and hence influence the rate of primary production.
Eulerian and Lagrangian views of vortex shedding are shown for various types of geometric obstacles, via streamfunction and passive tracer particle plots. The wakes contain vortices of the von Karman type in which vortices are alternatively shed from each side of the obstacle. Results of how interaction of wakes generated by the obstacles, depend on the distance between these obstacles, are also presented. Finally, examples with line vortex stretching terms are shown and compared with those resulting from cases in which flat bottom topography is used.
In particular, this model has been applied to the Canary Islands, where vortex shedding is accepted as a mesoscale phenomenon. Groups of islands have been chosen to show how their wakes interact, where they have been represented by different geometric shapes.

MESOSCALE DYNAMICAL REGIMES IN THE COASTAL OCEAN OFF IBERIA

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In situ intensive CTD surveys and current meter measurements off the western coast of Iberia combined with satellite observations during the observational phase of the European Union MAST-II MORENA Project, have allowed to identify two oceanographic regimes, alternating each year in the upper ocean, whose main meso- to submesoscale characteristics are as follows. During summer, typical hydrological and dynamical conditions related with the wind-driven coastal upwelling dominate: general uplifting of isopleths towards the shelf; fresher, colder and pigment-rich upwelled waters over the whole shelf with long filaments extending far (100-200 km) offshore, separated by strong fronts from the saltier, warmer and oligotrophic open ocean waters; equatorward surface flow - the Portugal Coastal Current - over the slope in the vicinity of the shelf break. The shelf-ocean exchange is dominated by offshore transport associated with the upwelling filaments, each one transporting about 1 Sverdrup (10^6 m^3 s^{-1}), and by shoreward return flows between each pair of filaments. From mid-autumn until late spring, a general situation of coastal convergence prevails, the most relevant transport mechanism in the upper ocean being the Portugal Coastal Countercurrent, flowing poleward over the upper continental slope along the seaward edge of the semi-permanent front which then separates the shelf waters from the open ocean.

SURFACE CIRCULATION IN THE NORTHEASTERN ATLANTIC REGION OFF IBERIA

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A study of the surface circulation near the western Iberian coast during 1993 and 1994, under the frame of the European Union MAST-II "MORENA" Project, was conducted using 16 drifters of the WOCE/TOGA type (drogues at 15 m depth) deployed mainly during November 1993. The drifters sampled a very heterogeneous velocity field with eddies of different scales but the mean currents were well represented by the mean velocity field and other related statistics in selected zones within the study region. From November 1993 until April 1994, a poleward surface current flowing along the upper continental slope and shelf break off western and northern Iberia was observed along more than 600 km, indicating that the northward Portugal Coastal Countercurrent is present not only in winter but also in spring. The mean speed in the Countercurrent was 13.5 ± 5.7 cm s^{-1} and the eddy kinetic energy (EKE) 42.0 ± 23.2 cm^2 s^{-2}. The eddy kinetic energy (EKE) near the Iberian coast was 48.8 ± 13.4 cm^2 s^{-2}, providing the largest part of the total kinetic energy as the MKE was 10.2 ± 4.8 cm^2 s^{-2}. Time and space lagrangian integral scales of about 3 days and 17 km were obtained. The mean zonal and meridional diffusion coefficients computed from the drifter data were of $(1.5\pm0.3)\times10^7$ cm^2 s^{-1} and $(1.5\pm0.4)\times10^7$ cm^2 s^{-1}, respectively, showing a degree of isotropy unexpected for a region so close to the shore.

THREE-DIMENSIONAL STRUCTURE OF A COASTAL MESOSCALE INSTABILITY

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An instability of the Algerian current (western Mediterranean) was sampled during a cruise of the MTP II-MATER MAST project on board the Spanish RV Hespérides in October 1996. It was identified, between 0° and 2°E, with infrared remote sensing, mainly as a meander of the current surrounding a coastal anticyclonic eddy, and associated with a secondary cyclonic eddy, upstream and seaward from the crest of the meander. In situ sampling of this instability was precisely located in relation to this surface signature by real time reception of satellite imagery. CTD, XCTD, XBT and ADCP profiles were recorded at high (a few km) horizontal resolution along several on-offshore sections, and 18 surface drifters were released for a Lagrangian tracking of the instability evolution. Upstream from the instability the current was, as usually, 55-60 km wide; whithin the anticyclonic part of the meander (alongslope length of about 150 km) it was shifted until 95 km offshore while, downstream from the instability, the width of the current was reduced to no more than 30 km. The cyclonic eddy reached a diameter of about 60 km and only affected the surface layer (about 100 m), but the coastal anticyclonic one appeared to be more than 1000 m deep.

TEMPORAL VARIABILITY OF THE SHELF CIRCULATION OFF THE EBRO DELTA AT MESOSCALE

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In the framework of the FANS project funded by the EU MAST-III Programme, several arrays of current meters were deployed at two transects north and southeast of the Ebro delta across the continental shelf and the upper slope for long-term time series observations. Monitoring on the southernmost transect began in November 1996 whereas observations at the northern transect were started in July 1997. The moorings, which consist of ADCP and RCM current meters placed at different depth layers, were deployed on bottom depths of roughly 50, 100, 300 and 600 m. The mid-shelf and upper slope current data exhibit alternation of two different circulation regimes: i) a "mesoscale regime", which is characterized by mean currents of the order of 15-20 cm/s to the S-SW and occurs when the shelf circulation is controlled by the Northern Current, i.e. the southward-flowing baroclinic jet linked to the Catalan slope front; and ii) a "high frequency regime" including sub-mesoscale oscillations (namely inertial, diurnal and multidiurnal oscillations related to the cyclicity of the local meteorological conditions), which takes place when the control exerted by the slope circulation on the shelf circulation is weak and the local forcings prevail. A detailed study on the spatial and the temporal structure of both regimes will be presented.

MESOSCALE EDDIES IN THE JAPAN SEA

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Role of mesoscale eddies in dynamics of the Japan Sea was revealed and both their space-time and kinematic parameters were determined on the basis of NOAA HRPT IR images (1993-1994) and satellite-tracked drifters data (1992-1995) analysis. The most typical diameters, mean orbital velocities and revolution periods of the eddies in the southern area were 90-140 km, 26-34 cm/s and 12-15 days, respectively, their translation velocity did not exceed 2 cm/s. Entrainment of warm (cold) water from south (north) by the eddies determined existence of the East Korean Warm Current, intensive zonal flow around the Yamato Rise and southward cold water intrusions. Seasonal variability of the observed circulation picture, its association with bottom topography and its correspondence with known schemes based on hydrographic data and numerical modelling are discussed.

BROAD BAND SPECTRUM OF MESOSCALE EDDIES IN THE GREENLAND AND MEDITERRANEAN SEAS RELATED TO DEEP WATER FORMATION.

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Recent lagrangian observations regarding mesoscale circulation variability, have been taken in the Greenland sea during the European Subpolar Ocean Project (ESOP2/MAST3) and in the Mediterranean sea during the SOFARGOS experiment (MAST2). Both regions, wellknown for producing deep waters during winter and spring seasons and subjected to a strong restratification in summer and fall, are revealing a surprising mesoscale eddy activity over long periods of time (several months). The mesoscale eddy field contains 10 times more kinetic energy than the mean field and it covers a very broad band from 5 to 50 kms diameter and 2 to 20 days period respectively. Potential energy seems to be the main source of energy for these eddies and, more likely, it originates from the diabatic cooling and heating at surface. In addition, there is an input of energy from the wind due to mechanical stirring initially and eventually from interaction with topography due to potential vorticity conservation at a later stage. In the first instance, the conversion of mean potential energy to eddy kinetic energy is the important phenomenon but, due to large diabatic effect related to strong air-sea interactions and internal mixing, it is still poorly understood. Most of the diagnosis based on baroclinic instability capable of converting potential in kinetic energy, are not entirely relevant in these instances since adiabatic assumption is not valid anymore. As we will show, a promising way to make progress, is to correlate the vertical component of the current with horizontal velocity fluctuations.

AGGREGATES DISTRIBUTION IN THE EASTERN ALGERIAN BASIN.

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Abundance and size distribution of suspended aggregates were studied in two eddies, in conjunction with the mesoscale dynamics during the ELISA-1 cruise (Eddies and Leddies Interdisciplinary Study in the Algerian basin, MATER MAST-3 project) in July 1997. Data were obtained by multiparametric sampling of the water column with a new instrument called the Underwater Video Profiler (UVP). It collects data on suspended particles >150 µm, abundance and size, turbidity, fluorescence, CTD and macrozooplankton vertical distributions. We sampled one algerian-current- induced deep anti-cyclonic eddy of 130 km in diameter and one small shear- induced superficial cyclonic eddy of 30 km in diameter. Both abundance and size of particles were higher in the cyclonic eddy and were positively correlated with the turbidity but not with the fluorescence. Further analysis will determine whether this is due to the presence of a regeneration system based on small plankton, or to the accumulation of detritus. Such eddies generate filaments entraining water from the proximity of Sardinian or Algerian coasts. This could explain localised increase of fluorescence and aggregates abundance on their edges. Although particles abundance data from this cruise are similar to those obtained in summer conditions in other oligotrophic regions, the spatial pattern of the aggregates distribution is different and seems influenced by the mesoscale dynamics.

COASTAL CURRENT INSTABILITIES IN THE PRESENCE OF TOPOGRAPHY

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The circulation of several basins can be strongly influenced by the instabilities of bouyant density currents. A linearized-analytical model and a 3-D PE numerical model are used to analyse and to understand the role of the topography on an unstable coastal buoyant current. The analytical approach allows to study the modifications to the baroclinic unstability produced by including a highly variable topography. When the slope is slight, only quasi-geostrophic modes exist. When the slope is very steep, others modes of ageostrophic type only appear with high growth rates and with very short wavelengths. The numerical approach allows us to study the physical mechanisms which control the interaction between the mean circulation, the mesoscale activity and the topography. Several phenomena are influenced by topography, including the amplitude of meanders, the displacement of vortices, the intensification of the deep cyclonic circulation, and, especially, the formation of an eastward mean current which is trapped above the slope. A numerical application to the Algerian Basin shows that the spatial scale of instabilities corresponds to the analytical results and to field observations. Also, this numerical simulation demonstrates the importance of accurately simulating the topography, a task achieved in this study using the generalized sigma co-ordinate system.

MEDDY GENERATION AND TRANSLATION MODELLED ON OCEAN AND TANK SCALES

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Measurements in the 1980's have revealed, that Mediteranean eddies are an important agent responsible for the effective transport of salt out of the coastal region off the Iberian Peninsula. Internal dynamics seems to control the propagation, stability and thus longevity of these strong isolated nonlinear vortices. In a numerical PE model an idealized meddy was implemented. To facilitate the direct comparison with laboratory experiments conducted with the "Coriolis" turntable at LEGI in Grenoble, the model has the same scales as the tank. Results of the comparison between model and tank experiments and the dependency of the evolving vorticity field on the Burger and Rossby number will be presented. Further the interaction between cyclonic and anticyclonic vortices and the interaction with different shapes of lateral boundaries both on tank and ocean scales are investigated. The datasets form a basis for testing the applicability of the tank experiments to oceanic scales. This work is a contribution to MAST3-CANIGO-CT96-0060.

Interaction effects in water dynamics of mezo- and synoptic scales on the White see shelf

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Surge-tide non-linear interaction effects in the tide current were researched with the help of Prandle & Wolf's "concurrently" model method. The interaction causes tide currents changes in dependence upon the phase of the surge relative to the tide. Those changes were reflected as vectors non-distorted & destorted by tide currents interaction. The scheme of vector differences field was found out to be similar to the one of surge currents components for the same moment of time. Vector differences sizes are 4-8 times less than corresponding surge currents components and their directions are the same on the surge rise phase and contrary on the fall phase.
Expedition researches in the straight Gorlo of the White sea showed the three mechanisms of eddies generation as the interaction effectes of tide movement, i.e. eddies formation: 1)during hydrological front meandering because of its interaction with tides; 2)because of horisontal stress unstability at river waters advection by reversive tide currents; here bifurcation "nuclears" are small in volume but comparatevely frequent in space (along the eastern coast of the straight) of river waters intrusion; 3)because of the straight coasts dampfing influence on progressive tide & surge waves from the Barents sea.

THE ROLE OF TRANSIENT EDDIES IN THE DYNAMICS OF THE ACC IN THE INDIAN SECTOR OF THE SOUTHERN OCEAN

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The eddy field from the TOPEX altimeter data shows a vigorous eddy field around the Crozet Plateau, especially around the northern branch and downstream of the Plateau. The important question is how transient eddies affect the mean flow? This problem has been studied using extension of the Eliassen–Palm flux concept for the three–dimensional case. The output of two fine resolution numerical models, namely FRAM and POP, has been used in these calculations. Transient eddies are found to be responsible in shaping the flow structure and transferring momentum in both the horizontal and vertical. The eddy flux of the potential vorticity has been split into rotating and divergent parts by solving a Poisson–type equation with appropriate boundary conditions, using iteration schemes. The rotational part is found to be quite large in the western and north–western part of the Crozet storm track.

THE AGULHAS CURRENT SYSTEM: THE INFLUENCE OF EDDIES ON THE TIME–MEAN CIRCULATION DIAGNOSED FROM GENERAL CIRCULATION MODELS

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The Agulhas Retroflection region is analysed in two ocean general circulation models, (FRAM and POP). It is shown that both models have two quasi–zonal jets, a northerly westward flowing jet and a more southerly eastward flowing jet, which act as the entrance and exits of the Retroflection region respectively. Both jets are shown to be baroclinically unstable, and have growth rates and wavelength consistent with those observed in both models. The energy analysis demonstrates that the westward jet is intensified by reynolds stresses, whilst the eastward jet shows that the reynolds stresses act to diffuse the jet. The divergence of Eliassen–Palm vector also gives evidence of the influence of eddies on the mean flow, both in the thermocline and in the deep waters. The structure of this influence is rather complicated. The westward jet is intensified by eddies but in the southern part of that jet in the waters deeper than 800 m there is a retarding of the mean flow by the eddies. In the eastward flow in the thermocline a retarding of the flow takes place, however in more deeper layers (deeper of 700 m) a strong forcing by the eddies occurs.

SEASONAL AND INTEARNUAL SIMULATIONS OF THE NORTH ATLANTIC VARIABILITY WITH A REGIONAL OCEANIC MODEL

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We use a regional version of an isopycnal ocean model (OPYC) to simulate the seasonal variability of the North Atlantic. The model used is an updated version of the OPYC with open boundaries. It consists in 10 isopycnal layers that simulated the deep ocean, topped by a mixed layer and coupled with a sea ice model. The domain cover $19°N$ to $65°S$, and $98°W$ to $17°E$, the grid resolution is $1.16°$ zonally and $0.52°$ meridionally. The seasonal evolution of the surface velocities as well as temperatures is satisfactory. An improved parameterization that includes the Neptune effect, allow us a better simulation of the dynamics, specially in the eastern boundary. Mechanisms of adjustement that maybe relevant to understand the decadal variability are also studied.

A NUMERICAL STUDY ON GRAN CANARIA ISLAND EDDIES GENERATION

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Satellite and field observations (Aristegui et al. 1994, Deep Sea Research)indicate that cyclonic and anticyclonic oceanic eddies are sequentially spun off from Gran Canaria Island. Two mechanisms has been proposed for Gran Canaria eddies generation. First mechanism is the perturbation of the mean flow (Canary Current) by the island. Canary Current flows NNE to SSW through the Canaries archipelago with reported geostrophic speeds up to 0.3 m/s (Reynold number up to 200) ,and might be expected to give rise to eddies. As proposed by Barton 1994(Annales Geophysicae), a second mechanism is the eddies generation by wind forcing. Due to trade winds perturbation by the island, strong wind shear lines are generated at the island wake, therefore eddies might be forced by the intense wind stress curl through Ekman pumping mechanism. Preliminary results of a quasi- geostrophic numerical model shows that both mechanisms may operate depending on the relative intensity of the trade winds and Canary Current.

FLOW PHENOMENA IN THE NORTH AEGEAN SEA DERIVED FROM SATELLITE DATA

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The Black Sea is connected to the North Aegean Sea via the straits of Bosphorus and the Dardanelles respectively. There is a significant surface layer flow from the Black Sea to the North Aegean Sea. The discharge pattern of the Black Sea Water origin (BSW) into the surface layer of the North Aegean Sea (NAS) is important to understand due to several environmental problems related to the dispersion of pollutants from various sources in the Black Sea towards the Mediterranean. Therefore, the knowledge of the hydrodynamic properties of the North Aegean Sea and especially the transport and spreading patterns of BSW is essential. Satellite data can provide important, qualitative information on circulation patterns and also a potential to quantify surface advective velocity fields. The surface water temperatures and temperature differences were used as a tracer for:

a) a qualitative description of the main hydrodynamic features of NAS, with emphasis on the discharge pattern of the BSW, analysed by a large number of NOAA-AVHRR data collected during one year, between 1995-1996
b) application of the Maximum Cross Correlation Method (MCC) to obtain quantitative information on surface advective velocities using sequences of NOAA-AVHRR data.

THE FORMATION AND PROPAGATION OF ENERGETIC EDDIES IN EQUATORIAL BOUNDARY CURRENTS

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From observations and recent numerical model results it is seen that the region of the North Brazil Current (NBC) is a center for the generation of large and energetic anticyclonic eddies. These eddies are generated near the retroflection of the NBC and propagate along the coast toward the Northeast. The physical processes responsible for the eddy generation and propagation are examined, first using theory and idealized process model studies, and then by an analyses of the realistic eddy-resolving numerical DYNAMO results.

THE INTERACTION BETWEEN GYRE SCALE AND LOCAL SCALE DYNAMICS IN THE AGULHAS REGION.

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The exchange of heat and salt between the Indian and South Atlantic Ocean via the Agulhas Current varies seasonally and interannually. Analytical and numerical studies have suggested that this interbasin exchange is largely sensitive to variations in the wind stress above the subtropical gyre of the Indian Ocean, in particular a meridional shift of the position of zero wind stress curl. However, it is still an open question how the local and far fields match and to what degree Agulhas leakage and ring formation are driven by local, gyre scale or global scale dynamics.

As a first step to solve this problem, the MICOM isopycnic coordinate model in a reduced gravity form is used. With this model, a study will be presented of the effect of gyre scale changes in the wind stress forcing above the Indian Ocean on local processes in the Agulhas region.

STRUCTURE OF THE WARM-CORE RING AND THE CONSERVATION OF ANGULAR MOMENTUM

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Meandering of strong oceanic fronts gives the origin of the most intense mesoscale eddies. The water in the central part of such eddy differs significantly from the ambient fluid. The available potential energy of the initial density slope is the main energy source of the following evolution of the eddy. The release of the available potential energy is attended by the radiation of gravity and Rossby waves. The nonlinear geostrophic adjustment scheme describing the evolution of the eddy is elaborated based on the conservation of angular momentum. It is enough to know the size of meander and the density stratification from both sides of a front for the reconstruction of full three-dimensional structure of a strong eddy formed after the detachment of frontal meander. We apply the nonlinear geostrophic adjustment scheme to calculate the structure of the warm-core ring traced during almost 150 days at the beginning of 80-ies. The distribution of density and velocity within the ring is calculated based on the archive density profiles to the left and to the right from the Gulf Stream front. Without any fitting the calculated density and velocity fields correspond to the observed ones presented by Joyce and McDougall, 1992 with the accuracy of 20 percents.

INFLUENCE OF DOUBLE DIFFUSION ON SYMMETRICAL BAROCLINIC INSTABILITY OF OCEANIC FRONTS

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We analyze analytically the problem of linear instability of 2D thermohaline baroclinic front taking into account vertical mass and momentum transfer caused by both double diffusion and turbulent mixing. Special attention is paid to a new type of baroclinic instability driven by coupled effect of double diffusion and baroclinicity. Being discovered by Kuzmina and Rodionov (1992) this instability in contrast to the McIntyre instability (1970) can exist with no limit on geostrophic Richardson number. A necessary condition for this new instability is nonzero Schmidt number, that is viscosity produced by double diffusion. We investigate the question of how the turbulence acts on this instability. The theory is successfully applied to describe intrusions in some oceanic fronts, namely the Subarctic Frontal Zone in the Western Pacific and the Azores Frontal Zone in the Atlantic.

ANALYSING THE INTERLEAVING IN OCEANIC FRONTS TO EVALUATE COEFFICIENTS OF TURBULENT MIXING

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CTD-data obtained in the Azores Frontal Zone and the Subarctic Frontal Zone in the Western Pacific are applied to study the relationship between characteristics of intrusions and mean parameters of thermohaline field. Self similar empirical dependencies between intrusion intensity and parameters of thermoclinicity and baroclinicity are constructed. Obtained from the analysis abrupt decrease of intrusion intensity with the reduction of geostrophic Richardson number is explained by the beginning of turbulence when salt fingers don't work any longer and "driving force" for intrusion motion disappears. This result is consistent with the conclusions of paper (Kuzmina, Rodionov, 1992) devoted to study the instability of quasigeostrophic front/current on the base of a linear, two-dimensional model of interleaving with mixing dependent on both salt-fingers convection and turbulence. Namely: the baroclinicity prevents double-diffusion interleaving by means of shear turbulence but generates intrusions due to the symmetric instability of quasigeostrophic current. The comparison between the new calculations using the model by Kuzmina and Rodionov together with the empirical self similar functions gives the possibility to evaluate turbulent mixing coefficients as a function of geostrophic Richardson number for the both fronts under investigation. The comparison of the proposed approach with the well-known method by Osborn and Cox (1972) are discussed.

MESOSCALE VARIABILITY OF THE NW MEDITERRANEAN SPRING BLOOM : PROCESSES AND PARAMETERIZATION

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In the NW Mediterranean Sea, sea-color images suggest that the eddies which participate in the restratification following deep convection interact with the spring phytoplankton bloom. The mechanisms for this interaction are studied using an eddy-resolving model, initialized with a patch of dense water surrounded by a stratified ocean. After a few days, meanders develop at the periphery of the patch. They are associated with strong upward velocities which cause shallow mixing-layer in the though of the meanders. This process locally enhances phytoplankton growth by increasing their averaged daily insolation. Further investigation is conducted to determine whether this mesoscale productivity enhancement can be parameterized. Two commonly used eddy parameterizations are tested in a coarser resolution context: the Gent and McWilliams (1990) parameterization (GM), and horizontal diffusion (HD). With GM, the redistribution of water masses leads to a shoaling of the mixing layer all around the convective area. As a result, productivity is enhanced similarly as when eddies are explicitly resolved. With HD, the convective area disappears due to diffusion of density across the isopycnals. The mixing-layer depth remains relatively deep, and productivity is significantly reduced. However, the above results only hold when the net heat-forcing is weak. In cases of strongly variable surface forcing, the impact of air-sea fluxes on the mixing-layer depth (and therefore on productivity) dominates over mesoscale effects.

FROM INSTABILITY WAVES TO TUNA IN THE TROPICAL ATLANTIC

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One region of the tropical Atlantic ocean stands out for its remarkable seasonal fishing of tuna : the PICOLO region [2N-5N,5W-25W]. This region experiences seasonal instabilities known as tropical ocean instabilities associated with highly energetic anticyclonic eddies with very specific velocity structures that affect the upper layers of the ocean. Hence it is likely that they greatly affect the ecosystem and may lead to tuna concentration. The PICOLO program has been designed to observe the characteristics of the dynamical/biogeochemical PICOLO region during a series of sea cruises, and to model the relationships between the dynamics and the ecosystem in order to understand the high tuna concentration. During the June-July 1997 PICOLO cruise, a tropical instability wave situation was sampled. Concurrent measurements of micronekton, zooplankton, phytoplankton biomasses, profiles of nutrients, temperature salinity and currents were collected. These measurements are used to describe for the first time, the 3-D structure of an anticyclonic tropical eddy in the Atlantic Ocean and its consequences on a particular surface enrichment that may, in turn, lead to tuna concentration. The data are also used to validate a high resolution coupled dynamical-biogeochemical NNPZD model of the tropical Atlantic ocean that successfully simulates the main dynamical and primary production patterns associated with instability waves.

THE ALGERIAN EDDIES

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As supported by altimetry, the Algerian Basin is the part of the Mediterranean Sea that is the most energetic at mesoscale. This is due to the unstable character of the Algerian Current that continuously meanders and generates eddies. Satellite images show that cooler and chlorophyll-richer waters upwelled where a meander leaves the coast describe an anticyclonic eddy within the meander. The meander and the eddy have a dimension fluctuating in the range 50-100 km, they propagate downstream at a few km/day, can be followed for weeks/months, and are often associated with intense (order of 50 cm/s) currents in the surface layer (about 200 m) mainly. A few times per year, whatever the season, especially energetic events are created. They seemingly have characteristics similar to the aforementioned ones in the surface layer, but are associated from their early stages with a relatively large (100-200 km) anticyclonic eddy in the whole deeper layer. Such an event detaches from the Algerian Current generally at the entrance of the Channel of Sardinia, where the deep isobaths turn seaward, and both the surface and the deep eddies come to merge. The resulting anticyclonic eddy often follows an anticlockwise circuit in the Algerian Basin, probably due to the beta-effect and the general shape of the basin. It is recognized for months as an isolated coherent structure often more than 200 km in diameter so that 2-4 such eddies can survive simultaneously as they fill the basin. Frequent and sometimes dramatic interactions thus occur between the eddies and their parent current that can spread seaward, at right angle from its normal, alongslope course, for months. These eddies also condition markedly the circulation of intermediate and deep waters in the whole Algerian Basin.

SUBDUCTION RATES IN THE SOUTH ATLANTIC USING A HIGH RESOLUTION NUMERICAL MODEL

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Mode waters are thought to be mainly formed in late winter by convection. The formation process and their ventilation in the thermocline are difficult to analyse with hydrographic measurements. A 40 years long numerical eddy-resolving (1/3°) experiment has been carried out for the South Atlantic, using seasonal forcing fields. The model mean circulation is in good agreement with the idea we now have of the South Atlantic general circulation. The formation of strong pycnostads in the upper ocean in the Subtropical Gyre in the simulation made us to consider processes of Mode Water formation. Given the small time and space scales resolved by the model, it was possible to quantitatively analyse the formation process of the Subtropical Mode Waters and their path within the Subtropical Gyre. To quantify their production, we computed instantaneous subduction rates (i.e. the mass flux going from the mixed layer into the main thermocline) for various water masses in the Subtropical Gyre. This computation gives access to annual mean subduction rates for different density classes which are consistent with the pycnostads found in the thermocline. Our analysis attempts to quantify the contribution of the eddy field to mode water formation and shows that eddies are most important in the preconditioning of the waters exposed to winter cooling.

VARIABILITY IN THE WIND-DRIVEN CIRCULATION IN THE NORTH ATLANTIC

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A reduced gravity shallow water model is used to study multiple equilibria and transition to periodic behavior of the wind-driven circulation in the North-Atlantic. Using a finite element representation and techniques of bifurcation theory, the effect of geometry on the mean flows and modes of variability is studied. There is a regime in parameter space for which two equilibria of the Gulf Stream mean path co-exist at the same forcing. Inter-seasonal and inter-annual variability of the mean path can be explained through instabilities and are shown to be related to those already found in simpler geometry. Patterns of variability are concentrated in the Gulf Stream and correspond to meandering and eddy shedding.
Additionally, high-frequency variability in the North-Atlantic has been studied using the 15 years of monthly mean sea surface temperatures from the Reynolds and Smith' dataset. Multi-channel singular spectrum analysis (M-SSA) has been used to obtain oscillatory modes of variability. The significance the modes that will be shown has been demonstrated on the basis of a Monte Carlo M-SSA algorithm. Data as well as results from the finite-element study show similar patterns of variability with comparable time scales.

INFLUENCE OF MIXING ON THE STABILITY OF OCEANIC CURRENTS

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We have investigated the influence of mixing on the stability of a coastal oceanic current. Theoretical results indeed show that diapycnal mixing can have a strong effect on the potential vorticity structure of a current and trigger baroclinic instability. The analysis we will present relies on the Charney-Stern criterion for currents stability and the Haynes-McIntyre impermeability theorem that governs potential vorticity evolution. Results from numerical models and experiments in rotating tanks that support our theoretical conclusions will be presented. Application to oceanic currents such as the mediterranean outflow will be discussed.

LABORATORY MODELLING OF TOPOGRAPHIC ROSSBY MODES

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Laboratory simulations of topographic Rossby normal modes (typical mesoscale topographically trapped oceanic features) are presented. The experiment was carried out in the "Coriolis" Rotating Platform at L.E.G.I. in Grenoble in the framework of the E.U. "Large Scale Facility Program". Preliminary numerical experiments have allowed to define an optimal topography and an efficient method of excitation of the modes. The main feature of the topography is a linear slope of 4x2 m delimited by two walls which allow for Rossby wave reflection and subsequent formation of normal modes. These motions, generated by a simple movement of a wavemaker and measured by means of sonic currentmeters and the "Correlation Imaging Velocimetry" method with laser induced fluorescence images, have revealed eigenfrequencies and spatial structures in very good agreement with the theory.

MODELLING SUMMER MARINE CIRCULATION OF THE GULF OF LIONS : USE OF AN EMBEDDED MODEL

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The Gulf of Lions can be considered as a complex region where several intense and highly variable hydrodynamic phenomena interact (Millot,1990). The objective of the present study is to investigate by the mean of a numerical model the influence of the Northern Current(N.C)on the hydrological and current regimes of the Gulf of Lions during summer period and to analyse the sensitivity of the circulation to the temporal variability of the open boundary conditions and atmospheric forcing. The model of the Gulf of Lions is embedded in a passive way in the general circulation model of the western Mediterranean Sea. The circulation and hydrology of the surface layers are seen to be quite sensitive to the temporal variability of the open boundary conditions and wind forcing. Embedding the Gulf of Lions model in the low resolution General Circulation Model allows for a better resolution of the mesoscale activity inside the Gulf : the behaviour of the NC is described in a more realistic way. The influence of the NC on the temperature evolution in the upper layer deserves interest. The northern areas are directly submitted to the heat supply by the NC whereas the downwelling area delivers heat to the open sea. The influence of the NC current can be seen as a flux of heat crossing from East to West the Gulf of Lions, strongly influenced by the coastal upwelling system which is not resolved by the coarse resolution model.

A POINTWISE ENERGY DIAGNOSTIC SCHEME FOR MULTILAYER, NONISOPYCNIC, PRIMITIVE EQUATION OCEAN MODELS

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Considered is the development of a pointwise energy diagnostic scheme for a multilayer, nonisopycnic, primitive equation ocean model whereby the various instability processes responsible for the highly nonlinear observed and modeled mesoscale flow structures commonly found in oceanic frontal areas may be discriminated.

The model considered consists of an arbitrary number of layers, and may be of finite depth or of the reduced gravity type. The concept of available gravitational energy replaces the conventional potential energy. Both conservative and nonconservative processes are considered.

Four basic instability processes are supported by the model: barotropic (horizontal shear), vertical shear, frontal and conventional baroclinic instability. While mean kinetic energy may be converted directly (by barotropic instability) and indirectly (via vertical shear) into eddy kinetic energy, there is no pathway by which mean potential energy can be directly converted into eddy kinetic energy. All such conversions must be routed through the eddy potential energy via frontal and/or conventional baroclinic instability processes. The scheme suggests that only barotropic and vertical shear instabilities are supported by a conventional multilayer reduced gravity model with constant density within layers.

MESOSCALE ANALYSIS IN THE ALBORAN SEA: THE IMPACT OF A RELOCATION PROCEDURE TO OBTAIN PSEUDO-SYNOPTIC DATA

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In the scope of the OMEGA project, cruises performed in the Alboran Sea are used to test the Omega-equation to compute vertical velocities based on synoptic hydrographic measurements. A previous study showed the need to relocate the data when the sampling of the cruise is sub-critical compared to the variability in time and space found in the Alboran Sea. Indeed, a change (i.e. relocation) in the position of the data may modify the analysis of the T/S fields and furthermore the vertical velocities.
To obtain pseudo-synoptic data at a given moment, we integrate a lagrangian motion equation to a 'mean sampling time', using geostrophic velocities. By means of a 3D PE model, this hypothesis was shown to be correct enough to increase the correlation on 'real' vertical velocities from 30% to 80%.
This algorithm is now applied to the fine scale OMEGA surveys in order to assess the impact of the vertical resolution of the analysis, the topography and the relocation on the vertical velocity fields. Furthermore, the relocation is validated against satellite thermal imagery.

EVIDENCE FOR THE INFLUENCE OF ATLANTIC-IONIAN STREAM FLUCTUATIONS ON THE TIDALLY INDUCED INTERNAL DYNAMICS IN THE STRAIT OF MESSINA

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On October 24 and 25, 1995, oceanographic measurements were carried out in the Strait of Messina by using a towed CTD (conductivity, temperature, depth) chain and a vessel mounted ADCP (acoustic Doppler current profiler). During these measurements an anomalous tidally induced internal wave field was observed in the Strait of Messina. In contrast to the climatological density distribution, the surface water of the Tyrrhenian Sea north of the strait's sill was found to be heavier on these days than the surface water of the Ionian Sea south of the strait's sill. As a consequence, while during northward tidal flow surface water of the Ionian Sea spread as a surface jet into the Tyrrhenian Sea, during southward tidal flow heavier surface water of the Tyrrhenian Sea spread, after having sunk to a depth of about 100 m, as a subsurface jet into the Ionian Sea. Both jets had the form of an internal bore, which finally developed into trains of internal solitary waves. Contrary to the usual situation, their amplitudes were larger north than south of the strait's sill. This anomalous tidally induced internal dynamics can be related to an anomalous path of the Atlantic-Ionian Stream which transported in October 1995 Modified Atlantic Water (MAW) into the southern part of the Strait of Messina.

DO WE REQUIRE ADIABATIC DISSIPATION SCHEMES IN EDDY RESOLVING OCEAN MODELS?

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Use of horizontal diffusion of temperature and salinity in numerical ocean models causes spurious diapycnal transfers—the "Veronis effect"—leading to erosion of the thermocline and reduced poleward heat transports. Here we derive a relation between these spurious diapycnal transfers and the dissipation of vorticity gradients in an ocean model. Increasing model resolution does not significantly reduce the diapycnal transfers, because vorticity gradients cascade to smaller scales and must ultimately be dissipated to maintain numerical stability. We confirm this result through a series of idealised experiments with a primitive-equation ocean model at resolutions between 1° and 1/8°.
We therefore conclude that adiabatic dissipation schemes are required even in eddy-resolving ocean models. We propose and implement a new biharmonic form of the Gent and McWilliams scheme, which adiabatically dissipates at the grid scale while, preserving larger-scale resolved eddies and boundary currents.

THE ORIGIN, STRUCTURE AND DECAY OF A SUBSURFACE EDDY IN THE GREENLAND SEA STUDIED BY IN-SITU MEASUREMENTS AND NUMERICAL MODELING

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During May 1996 the hydrographic structure of the Greenland Sea was surveyed from aboard RV Valdivia. CTD measurements indicate that, over most of the area, the convection during the previous winter was confined to the upper 500 m of the water column. However, near 75°N, 0°E/W, an isolated feature with a diameter of about 15 km was observed, that showed an extremely homogeneous water column between 500 m and 2000 m depth. Potential temperature and salinity were -1.0° C and 34.875 and constant within 0.001° C and 0.001, respectively. The analysis of the geostrophic currents as calculated from the observed density field indicate an anticyclonic rotation of the water column. The origin of this subsurface eddy is investigated. The region was free of ice during most of the previous winter season, suggesting that thermal convection triggered by strong surface heat fluxes was responsible for the generation of the chimney. The collapse and decay of the chimney was simulated by means of a numerical multilayer 'frontal' model which, due to a technique for the numerical treatment of moveable lateral boundaries, allows for the simulation of localized water masses. It is found that these eddies persist as coherent structures in the deep ocean for several months.

MULTIVARIATE ANALYSIS OF SEASOAR AND ADCP DATA IN THE WESTERN ALBORAN SEA: SYNOPTICITY TEST AND SENSITIVITY TO REFERENCE LEVEL AND ANALYSIS PARAMETERS

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In October 1996 a cruise onboard BIO Hespérides was conducted in the Western Alboran Sea as part of the EC OMEGA project (MAS3-CT95-0001). A 80x100 Km^2 domain was sampled using a SeaSoar and a VM-ADCP, resulting in a set of 400 m deep profiles separated 4 km alongtrack. Three surveys were performed, spending 3 days to complete each one. Because in a frontal region derived variables as the vertical velocity are expected to be sensible to short time scales, we carried out a synoptic test to check whether sampled mesoscale structures changed slowly enough during the sampling period as to consider the survey as "synoptic". A second test showed that results were very sensible to the reference level chosen for geostrophic computations, due to the large ageostrophic component of the velocity field in the upper 150 m. Finally, the sensitivity of vertical velocities to the analysis parameters was also checked. We conclude that a statistical multivariate analysis is a valuable tool to infer the 3D motion field from hydrographic and ADCP data. Provided the analysis is carried out in an optimal way, vertical velocities can be estimated with an accuracy of about 30%.

DRIFTERS OBSERVATIONS OF A COLD FILAMENT IN THE NORTHWEST AFRICA UPWELLING AREA

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Two Lagrangian drifters were deployed the lasts days of September 1997 during the Filament Cruise as a part of the CANIGO project. These observations are used to describe the two-dimensional structure of the surface flow in the Cape Ghir area where a cold water filament is usually observed. The first buoy (03513) was released next to the coast at position 30.995 N 10.167 W on September 28, and the other one (03510) was deployed one day after at position 31.186 N 11.076 W. The drifters positions were obtained via service Argos at an average of six times per day. The data transmission from drifter 03513 was stopped on November 9 and drifter 03510 on December 4. Drifter tracks are compared with coincident sea surface temperature (SST) images and wind data in order to observe the relationships between cold surface features, surface motions and meteorological conditions.

LABORATORY STUDY OF THE INTERACTION OF AN UNDERWATER CURRENT AND A CAPE

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On the 13 m diameter rotating platform, we studied the interaction of an underwater current and a cape. When the upstream condition is a stable current (i.e. in geostrophic balance) and whatever be the cape angle (160°, 135°, 120°, 90° or 70°), there is only the appearance of an anticyclonic vortex, the diameter of which grows linearly with time. When the upstream condition is unstable there is lenses production upstream or downstream the cape and indeed at the cape itself. For the simulation of the flow around Cape St Vincent, we choose the angle at the 1000 m isobath (i.e. 70°) as representative of the cape influence upon the Mediterranean intermediate water. Then we were able to visualize and measure the flow with great accuracy using the Correlation Image Velocimetry technique. From the velocity fields, it is possible to compute the vorticity field at various time-steps and see the formation and separation of an anticyclonic lense from the cape. This work is a contribution to MAST3-CANIGO-CT96-0060.

DISCRIMINATION OF INSTABILITIES ON THE FRONT BETWEEN THE NORWEGIAN ATLANTIC CURRENT AND THE NORWEGIAN COASTAL CURRENT

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Mesoscale variability in the Norwegian coastal current (NCC) has been documented in a sequence of NOAA satellite images and can also be reproduced in numerical models provided the resolution is fine enough to resolve the horizontal density front between the NCC and the Atlantic water (AW). The model employed is a primitive equation, multilayer, non-isopycnic model. A density front with a varying mixed layer depth consistent with observations is given as initial conditions. The model results indicate that the instabilities in the NCC result in the formation of meanders and eddies with wavelengths of 50-100 km and northward propagation speeds of 10-20 cm/s.

An energy analysis scheme is applied to discriminate the various competing processes. The energy is first partitioned into kinetic and potential energy and then into components associated with the mean and the fluctuating motion, respectively. The conversion terms between them are identified as frontal instability, mixed frontal-conventional baroclinic instability, barotropic instability and Kelvin-Helmholtz instability processes. The energy analysis reveals that the mesoscale features are maintained by baroclinic instability processes, specifically the frontal instability, while the barotropic instability associated with velocity shear between the southward AW over the western slope and northward NCC along the coast plays a minor rule.

A DYNAMIC METHOD FOR HORIZONTAL DISTRIBUTIONS OF SEA WATER PROPERTIES

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The horizontal distribution of a sea water property, such as temperature, salinity, density, etc, in a region has been usually represented by contour maps. They are obtained by intrpolating in situ measurements at certain points over all the region. Contour lines can be defined as boundary lines of the areas in which the values are lower (or higher) than a fixed reference value. It is assumed that the values at observation points are exact and the interpolated values have an error which increases with the distance to the closest observation.

Satellite pictures show the "real" shape of sea surface distributions of variables such as temperature. These shapes also suggest the behaviour of the water motions. A comparison between satellite images and contour maps obtained with in situ measurements are used to calibrate the satellite images but shapes usually did not match because interpolation methods do not take into account water motions.

The dynamic method proposed an alternative interpolation method for horizontal distributions that takes into account the geostrophic component of the water motion, which in most cases is highly significative. It can be applied with data of most oceanographic cruises, based on CTD (Conductivity, Temperature, Depth) measurements at fixed stations. The method is illustrated with some examples which show that shapes of the contour lines produced are in a good degree of agreement with the satellite images.

ABOUT THE FORMATION OF MESOSCALE STRUCTURES ON THE BRAZIL CURRENT CONFLUENCE

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The mechanisms of low salinity water discharge from the RÝo de la Plata to shelf and from the shelf water to the open ocean are studied in the Brazil Malvinas (Falkland) Confluence Zone (BMC). Atmospheric perturbations and fundamentally the wind fields, and the eddy formations are components of these mechanisms. Anticyclonic eddies and meanders in the Brazil part of the Confluence has been described (Legeckis, Gordon, 1979). This paper deals with the possibility that the passage of atmospheric fronts and the associated wind field perturbations influence on cyclonic eddy formation in the Malvinas part of the Confluence. Apparition of cyclonic eddies in the Malvinas part of the BMC, jointly with the existence of anticyclonic eddies in the Brazil part of the BMC must be accompanied by rude increase of the surface current velocities and also, by the formation of eddy systems with ?fungous? structure. These fungous eddy systems have been analysed by satellite data (Fedorov,1988). This paper supposes that the fungous eddies are forced by the atmospheric processes, which are better expressed during the transitory seasons of the year and in Winter. These eddy systems can contribute to the increase of Subantarctic water advection, transportation the Malvinas current to North, and to the increase of the discharge of low salinity water from shelf to the open ocean. The trajectories of the low salinity water discharge which lie on the ocean fronts serve as an indicator for: Satellite data decodification for BMC zone, fishery conditions variability, and for the study of the fitoplankton redistribution in this area. To asses on the phenomenology of eddy formation, a synoptic approach was employed.

REPRESENTING THE EDDY FIELD IN A HIGH RESOLUTION MODEL OF THE IRMINGER SEA

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One source contribution to the North Atlantic Deep Water is the Denmark Strait Overflow Water (DSOW) which crosses the Denmark Strait as a bottom current. Earlier observations and numerical studies of the overflow area revealed cyclonic eddies with length scales of tens of kilometers or less in the vicinity of the overflow region. These eddies were identified as the surface signal of the deep water flow along and downslope the topography. While the interaction of the cyclones and their anticyclonic counterparts with the deep water overflow is not yet fully resolved, the representation or parameterization of these eddies in numerical models will be of crucial importance for understanding the overflow process in three dimensional circulation models. In this presentation, first results from a high resolution, z-coordinate model of an idealized basin with rough characteristics of the Irminger Sea are shown. The model features both, cyclones and anticyclones. Nevertheless, because the grid scale is greater than the baroclinic Rossby Radius, the model does not completely resolve the eddies. Thus the eddy properties depend on the subgridscale parameterizations. The effects of different mixing approaches on the dynamics of the eddies are discussed.

DIRECT OBSERVATIONS OF LOW FREQUENCY FLUCTUATIONS IN THE DEEP EQUATORIAL ATLANTIC

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Low frequency current fluctuations in the deep central equatorial Atlantic are studied using two year long current meter measurements recorded from November 1992 to November 1994. Current meter moorings were located at about 15° W of longitude and at 1° of latitude on both sides of the equator. The five sampling depths varied between 1700 and 3950 m.

Spectral analysis of the current meter records gives evidence of energetic annual and semi-annual variability for both east u and north v velocity components from 1700 m up to 3950 m depth. The sum of the annual and semi-annual oscillation amplitudes are about 10 cm s^{-1} for u but less than 5 cm s^{-1} for v at 1700m. In addition, the meridional component has energy in a spectral band centered on 40 $days^{-1}$. Long baroclinic Rossby waves can explain the low frequency signal (variability at higher frequency is probably due to Yanaï waves). Projection of the current data on the first five baroclinic vertical modes shows that the first mode is not prevailing compare to the others. The fitting of a sum of Rossby waves to the data moreover proves that odd meridional modes are dominant in the signal. Results from a Primitive Equation numerical model are used for comparison with in situ data.

The interactive relation of water column structure and mesoscale circulation in the Cretan Sea during the last decade.

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The Cretan Sea (S. Aegean) has undergone dramatic changes in the last decade; the most significant development has been the gradual filling of the deep part of the basin with very dense (reaching 29.4), salty (S up to 39.1) water, the so-called Cretan Deep Water, that eventually overflowed through the sills of the Cretan Arc Straits and replaced waters of Adriatic origin at the deep and bottom layers of the Eastern Mediterranean. This massive outflow was balanced by the enhanced intrusion of older waters from the Eastern Mediterranean. The latter, less saline and cooler waters occupied the intermediate layers (200-500 m) of the Cretan Sea. The modified structure of the water column significantly changed the internal Rossby radius of deformation and its seasonal variability. Since the beginning of the last decade, the mesoscale circulation of the Cretan Sea also exhibits a profound stability, not characteristic of the region in the eighties: three eddies, two cyclones and one anticyclone have been the dominant circulation elements for the last five years. This work proposes that the stability of the mesoscale circulation is directly related to the observed changes of the water column; furthermore, we examine the possibility of a positive feedback mechanism that would enhance both formation and stability of the mesoscale eddies in the region.

OA5 Open session on coastal/shelf-sea dynamics

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COASTAL UPWELLING AS INDICATOR OF ATMOSPHERIC PROCESSES

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The study of long-term variability of oceanographic characteristics of the World Ocean is worth to carry out in the regions sensitive the most to ocean-atmosphere interaction, for instance in the regions of seasonal and all-the-year-round upwelling. The Caspian sea is the most convenient object for such a study for the absence of connection with the World ocean allows to exclude circulation factors influencing processes in the Caspian sea and to look for cause of long-term fluctuations in atmospheric processes. The analysis of long-term variability of monthly averaged sea surface temperature (SST) for the summer period was carried out after the coastal observation data from 1941 till 1990 for 3 regions of the Caspian sea: with seasonal upwelling, with episodic upwelling and without evident upwelling. The results of analysis showed that long-term variability is expressed the most only in the area of seasonal coastal upwelling, i.e. at the eastern coast of the Middle Caspian basin. It was displayed that during last 50 years upwelling in this area strengthens that was reflected in decrease of monthly averaged SST for August unlike other regions where opposite tendency is observed. Upwelling enhancing is most likely connected with the intensification of the alongshore southern wind. Such intensification of the alongshore wind near California, Peru and other regions was mentioned in the work [Bakun, 1990]. Spectral analysis of monthly averaged SST for August revealed fluctuations with the periods of 2-3, 4-5 and 10-12 years at that the intensity of these fluctuations in the region of seasonal upwelling is several times larger than in other regions. Similar periods are found out in large-scale circulation system of the North Atlantic. All statements proposed above allow to put forward a hypothesis about the reason for distinct long-term SST fluctuations as the result of strong sea response in the area of seasonal upwelling to large-scale atmospheric processes.

LONG TERM PHYSICAL VARIATIONS OF WATERS IN A DEEP BASIN OF THE AEGEAN SEA (Saronikos Gulf, GREECE).

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Data from 37 Oceanographic Cruises collected during the last 10 years (1987-1996) in the Saronikos Gulf, by the National Centre for Marine Research, are evaluated. The existing five water masses are examined; the Elefsis Bay, the Inner, Central, and Outer Gulfs and the Western Basin. The transeasonal Physical variations in the deep water of the Western Basin of the Gulf, verify the existence of the almost stagnant water below the depth of about 200m, with a temperature of about 13.20°C and salinity around 38.95psu. Moreover, it seems that the water of slightly lower salinity entering from the open Aegean Sea might disrupt the general tendency of increased salinity with depth, at some depth intervals.

FAR FIELD OF INTERNAL GRAVITY WAVES IN A STRATIFIED OCEAN OF VARIABLE DEPTH

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Theoretical research of the problems associated with propagation of internal gravity waves in a stratified ocean requires account for the slope of the ocean bottom. The propagation of internal gravity waves is analyzed in a layer of arbitrary stratified water of variable depth. The exact analytical solution of this problem using separation of variables is possible only, when the profiles of density and the bottom topography are specified by simple model functions. If the ocean depth changes slowly compared with internal wave length, which is typical to the ocean, it is possible to use the modified method of the geometrical optics: "vertical modes - horizontal rays". A uniform asymptotics of the far field of internal waves is constructed for the motion of a point source of mass in a arbitrary stratified fluid with slowly varying bottom. The obtained solutions describe the far field both in the close vicinity of wave fronts for each separate mode and far from wave fronts. These solutions present the expansion in terms of special waves, Airy or Frenel waves, whose argument is determined from the solution of the corresponding eikonal equation. The amplitude of the wave field is determined from the law of energy conservation along the ray tube. The peculiarities of the phase structure of the wave field are analyzed for real distributions of the stratification and forms of bottom topography both numerically and analytically. Analysis of spatial blocking effects for individual wave fields components is performed as an example. This research was supported by Russian Foundation of Basic Researchers, Grant 96-01-01120.

INTERNAL WAVES IN GULF OF RIGA: OBSERVATIONS AND LINK WITH MODEL OF VERTICAL TS STRUCTURE

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Definitive two-layer stratification exists in the Gulf of Riga during April-November allowing formation and propagation of internal waves on the interface.
Several series of continuous (up to 2-days long) temperature and salinity measurements at the depth of pycnocline were performed in the Gulf by a CTD sound with time resolution 15 seconds. Simultaneous vertical TS profiling have been carried out.
Amplitude and main frequencies of oscillations on the interface have been determined. The trains of short-period (2-4 min.) internal waves as well as internal seiches with period of approximately 12 hours have been resolved. Determined period of internal seiches is in agreement with that calculated from basin geometry while period of short waves corresponds to that obtained from local Brunt-Väisälä frequency.
Model of vertical TS structure has been applied for the measurement periods. Meteorological data of high time resolution including in-situ measurements has been used for model forcing. Model results give the overall trend of the depth of pycnocline simplifying removal of this trend from the measurement data and resolving of the periodic internal oscillations.

High-resolution observations of currents and hydrography in the Kattegat.

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The Kattegat is a part of the transition region between the low-saline Baltic Sea and the North Sea, dominated by water of oceanic origin. The mixing between the low-saline surface water and the high-saline deep water in the Kattegat is of great importance for the salinity of the deep water entering the Baltic and thus a key process in the modelling of the Baltic sea. The topography of the northern Kattegat is characterised by a deep channel (80 - 100) in which there are several elongated deep holes down to more than 140 m. The interaction between the stratified flow and these topographic features can b e expected to be of importance for the deep water mixing. To study this, the velocity and the density fields have been investigated with high spatial and time resolution at the site of a smal-scale depth in the northern Kattegat (the Alkor Tiefe). The horizontal scale is of the order 1 km and the depth is 140 m, compared to about 80 m which is found in the surroundings. Two field experiments were performed, one during a period with weak stratification and one during a period with a strong two-layer stratification (the usual case in the Kattegat). Each observation was carried during about 4 days with the use of 4 bottom mounted profiling Doppler current meters recording at 5 minutes intervals.and with a vertical resolution of 4 m. The ship was continuously surveying the area by means of ship-born ADCP and CTD casts. Analyses of the velocity and density fields indicate a strong interaction with topography on the scale of the deep hole forming baroclinic tides and other phenomena. This interaction is explained using simple analytical arguments.

SHOALING OF INTERNAL SOLITARY WAVES ON THE MALAY SHELF IN THE ANDAMAN SEA

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Synthetic aperture radar (SAR) images acquired by the European Remote Sensing satellites (ERS 1/2) over the southern Andaman Sea have been analyzed to investigate tidally induced internal waves in the area. Over the deeper part of this oceanic region, surface manifestations of groups of rank-ordered, large-amplitude internal solitary waves are observed on SAR images, which, generated at shallow banks in the western part of the Andaman Sea, propagate eastward toward the Malay peninsula. On the contrary, SAR images acquired over the shelf of the Malay peninsula often show sea surface manifestations of groups of shorter, irregular internal waves. Their fronts are visible on SAR images either as dark or bright lines, suggesting that the leading waves consist of elevations or depressions of the undisturbed pycnoclines, respectively. The effects of stratification and water depth on the evolution of shoaling internal solitary waves are studied by using weakly non-hydrostatic, numerical two and three layer models. Numerical simulations carried out by assuming different stratifications indicate that in a two layer ocean where, over the shelf, the upper layer is thicker than the bottom layer, a shoaling internal solitary wave of depression evolves, after disintegrating into a group of dispersive waves at the shelf break, into solitary waves of elevation. On the other hand, in a three layer ocean characterized by the presence of an additional pycnocline close to the sea surface, solitary waves of depression can also evolve over the shelf, depending on the specific stratification of the water column.

EFFECTS OF THE BOTTOM BOUNDARY LAYER ON THE VERTICAL STRUCTURE OF CURRENTS IN THE NORTHERN ADRIATIC

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A 2 dimensional Princeton Ocean Model version has been used in a section of the middle Adriatic Sea to study the bottom boundary layer influence on currents. The hypothesis is that the bottom stress partially drives the longitudinal gradients of isopycnals across the Adriatic Sea section, especially in the winter-spring transition. This mechanism is known as pressure compensation effect and is the result of coupling the baroclinicity of the flow field with the bottom stress.
We prove that the pressure compensation effect is at work in the Adriatic and it results in the strengthening of the cyclonic circulation in the basin under certain circumstances.
The effect of the bottom boundary layer parameterization, such as roughness length, has been studied through sensitivity experiments.
It is found that for a realistic parameter range (1-5 cm) the bottom stress effects are the same, but the time scale of the flow adjustment changes. In conclusion we show that the bottom stress acts as one of the essential forcing of the vertical structure of the currents in the Adriatic basin.

OBSERVATION AND MODELISATION OF VORTEX FORMATION IN THE CASE OF THE INTERACTION OF THE MEDITERRANEAN OUTFLOW WITH SUBMARINE CANYON

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The SEMANE'97 experiment at sea was conducted to determine the formation sites of the Mediterranean Eddies on the Iberian shelf, from the canyon of Portimao to the west of Tagus Plateau. Its hydrological and currentmeter data was processed and studied to assess the influence of bottom topography on flow stability and vortex formation. Strong unstable events were observed such as several meanders aligned along the off-shore edge of the lower core of the Mediterranean Outflow downstream off the Portimao canyon. At the same time, north of St Vincent Cape, coherents structures were in formation.
It shown that bottom topography has an essential influence first at destabilizing the Mediterranean water undercurrents, then in shedding eddies and filaments. Eddies produced over canyons are the result of a mixed barotropic and baroclinic instability steered by the canyon. A cause for the vertically phase-shifted meanders to appear on the vein should be searched in potential vorticity reversals what we have already shown with SEMANE'95 data.
A simple stratified quasi-geostrophic model is used to highlight these processes and to quantify their sensitivity to changes in the physical parameters. First an analytical study of the stability of the modelled flow is done to check if the flow is naturally stable and then, only the stable configurations are numerically processed. With the Contour Advective Semi-Lagrangian Contour Surgery model of David Dritschel, the interaction of an along-shore current with a transverse canyon is analysed. Therefore we can determine the physical parameters that lead to the formation of a vortex over a submarine canyon. Perturbations (stationnary waves with alternative or in-phase oscillations of each core, widening or narrowing, meandering with or without vortex expulsion) are sorted in parameter's spaces (width and speed of the undercurrents, stratification, canyon geometry).

SURFACE HEAT AND WATER FLUXES MEASUREMENTS

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Continous measurements of atmospheric radiation, net longwave flux through the air-sea interface, sea surface temperature and meteorological parameters started in December, 1997. Aandera sensors for global and net radiation and for other parameters were mounted on a platform over the sea at the coastal station Split-Marjan cape.
First results obtained from one month of measurements were used to describe distribution in time of relevant bulk variables and to calculate surface heat and water fluxes, using bulk parametrisation formulae.
Heat and water fluxes calculated from bulk formulae were compared to the measured fluxes and results were discussed.

EARLY RESULTS FROM A 3-D PRIMITIVE EQUATION MODEL APPLIED TO THE BALTIC AND THE NORTH SEA

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A three dimensional primitive equation model based on the Cox-Bryan model is set up in the region of the Baltic and the North Sea. The model is run on a 216 processor CRAY T3E. The model development is mainly done within the Swedish Regional Climate Modelling Programme (SweClim) and will be coupled with a regional atmospheric model in the near future.

HYDROGRAPHY OF THE PECHORA SEA, THE SOUTHEASTERN BARENTS SEA

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Abstract

The Pechora Sea, is one of the areas of the Barents Sea characterized by the widest amplitudes of many parameters, such as salinity, temperatures of both water and air. During wintertime, dense water is formed over the Pechora Sea and it is almost every year ice-covered.
In the Pechora Sea different water masses mix and undergo gradual transformations. These water masses are: (1) the strongly diluted water of the White Sea and Pechora Currents; (2) the much more saline and warm Atlantic water of the Kanin and Kolguev-Pechora Currents; (3) the Barents Sea water from the north, (4) the cold water from the Kara Sea, and (5) the melt water from ice and riverine discharge. All these different water masses meet in the Pechora Sea and hence makes it hydrographically very intresting.

ANALYSIS OF THE BLACK SEA LEVEL OSCILLATIONS IN THE DIFFERENT PLACES OF THE NORTHERN PART OF THE COAST

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Statistical analysis of the long period (more then 100 hundred years) daily observations of surface-level oscillations in the different places (47 stations) of the Northern part of the Black Sea coast is presented. By means of a standard statistical processing of time-series data it was discovered that practically in the all places (except a few of them) the general trend of the sea level takes place. This trend is directed to the enlarging of the mean sea level (about several millimeter per year). The sea level oscillations with respect to the mean level demonstrate Gaussian distribution on amplitude. The characteristics of this distribution (dispersion, maximum deviation, etc.) are evaluated for the different places of the Black Sea Northern coast.

3D LINEAR ANALYTICAL MODEL OF INTERNAL TIDE GENERATION ON COASTAL MARGINS

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The internal tide on coastal margins is known to be the main generation mechanism of non linear internal waves such as solitary waves. This knowledge is important because of the internal mixing induced. Thus, the internal tide has to be predicted with sufficient accuracy to be introduced as an initial condition in non-linear evolution wave models. In this paper, we present a three dimensionnal linear wave model of internal tide generation due to the interaction of the barotropic tide with both the shelf bathymetry (represented by a step) and the stratification (assumed to be a two-layer). Earth rotation is taken into account and the coast is supposed to be a perfect absorber (no reflection). The new feature in this model compared to previous ones is the influence of the incidence angle of the barotropic tide. The model is compared with measurements collected during summer 1996 on the Malin Shelf within LOIS/SES experiment. Results show that the angle of incidence of the M2 barotropic tide is of great importance. On the Malin Shelf, this angle is about 80° from the normal to the shelf break. Considering this angle, the predicted M2 internal tide amplitude and wavelength are in good agreement with the measurements whereas neglecting it, the predicted amplitude would be twice that observed.
This study is supported by the British Council and the E.C. under MAST III project MORSE (N° MAS3-CT95-0027 DG12 ESCY).

The Rhine Outflow Studied by ERS1/2 SAR Imagery and Numerical Simulations

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Radar signatures of the Rhine plume front visible on synthetic aperture radar (SAR) images acquired by the First and Second European Remote Sensing Satellite (ERS1/2) over the Rhine outflow region, in the southern North Sea, are analyzed. It is found that form and location of the freshwater plume fronts, which can be identified in the SAR images as curved lines of enhanced radar backscatter, mainly depend on the phase of the semi-diurnal tide, on the neap-spring tidal cycle and on the mean Rhine discharge.

The frontal structures of the Rhine plume visible on the ERS1/2 SAR images are compared with results from numerical simulations carried out by using a new two layer 'frontal' numerical model. The model is forced by imposing tidal and residual transport as well as mean river discharge at the open boundaries. Numerical simulations are carried out with different tidal current velocities, residual current velocities and mean river discharges. The results of the simulations show that, due to the interaction with the semi-diurnal tide, the Rhine outflow pulsates. This pulsation is responsible for the generation of freshwater plumes at the Rhine mouth. Form and location of the outflow fronts associated with the river plume are mainly determined by the phase of the semi-diurnal tide. The area which is enclosed by the outflow front is mainly linked to the magnitude of the tidal current and to the mean river discharge.

THE RELATION BETWEEN COASTAL SEA LEVEL AND SLOPE CURRENTS

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The inflow of Atlantic Water to the Nordic Seas has a significant effect on the coastal sea level in Norway and other northern European countries. Or is it the opposite? The geostrophic balance for low frequency (5-day periods or more) has been demonstrated using coastal sea level observations corrected for air pressure and coastal steric heights. The latter includes the long-term effects of regional winds on the displacements of buoyant coastal water. Current measurements are taken along the slope near the location where the maximum current is stabilized by the sloping bottom. There is nearly a linear correlation. Maximum currents are estimated to within an accuracy of 10%, and agree well with the stability limits imposed by potential vorticity dynamics on the bottom slope. The methods used need an accuracy of about 2 cm in amplitude and hourly in time (for accurate integration), and lie beyond the present capability of satellite altimetry. The noise in the observations is on the order of 5 cm, due to physical processes that are not taken into account in the simple geostrophic balances, and the limited time resolution of the coastal hydrography. The data show that the coastal sea level rises before the slope current is developed. The phase lags imply that the flow is generated across and along the shelf like a kinematic wave, as the inflow of Atlantic Water builds up the slope jets across the topography. We conclude that the sea level fluctuations in the North Atlantic are important for the dynamics of the currents over the entire northern European shelf.

CONVECTION OVER A CONTINENTAL SHELF AND SLOPE

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A series of laboratory experiments was conducted to simulate the effects of cooling or brine rejection on the surface of a coastal ocean in the presence of rotation. Heat loss at the ocean surface was modelled by heating from below with a buoyancy flux applied to a circular portion of the base of a cylindrical tank, rotating around the vertical axis. The working volume was closed by an inverted model of a shelf and slope topography.

After the start of the buoyancy forcing, the average temperature in the actively convecting region initially increases linearly with time, but slows down once a lateral heat flux is generated by baroclinic instability at the edge of the convecting region. Due to the presence of the sloping bottom, the baroclinic eddies do not move away from the shelf break, but precess anticyclonically along the slope. A steady state is eventually reached when the lateral heat flux balances the (vertical) heat flux due to the forcing. The results differ from previous work in either unbounded or constant depth environments. It is shown that the steady state density anomaly, the time to reach this steady state as well as the eddy velocity, characterising the lateral exchange process, are all a function of the strength of the background rotation. These results are consistent with the description of the lateral exchange process by eddy diffusion.

DEEP WATER VENTILATION TRIGGERED BY TURBIDITY CURRENTS: NUMERICAL INVESTIGATIONS

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Deeper waters of the ocean can be ventilated by turbidity currents forming on shallow shelves, which are reservoirs of recent sediments of either fluvial or glacial origin. When a storm induces stirring of shelf waters, a density increase due to the contribution of sand and silt may allow for sediment plumes descending the continental slope. Sediment plumes can be further enforced by entrainment of bed sediments during their descent. When the density of a plume equals the density of ambient waters, the plume leaves the slope and restratified within the ambient ocean at the respective intrusion level. Once the plume slows down, sediment settling allows for upward directed convection because plume waters become lighter than waters above. This facet of deep water ventilation triggered by turbidity currents is demonstrated by means of simplified two-dimensional plume studies. The possible effect of sedimentation-driven convection is investigated with both (1) a simple convective adjustment scheme and (2) a high-resolution nonhydrostatic convection model. In our studies a shallow sediment plume (~ 50 m thick) triggers convective stirring over a depth range of > 500 m of deep waters. In summary, the studies suggest that turbidity currents contribute to the ventilation of intermediate or deep waters.

OA5

Validating a several years model run by using temperature and salinity data

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Many different 3-d model studies, focussed on baroclinic prognostic studies have been carried for the North Sea and the Baltic Sea during the last years. However, prognostic runs for several years, without restoring to climatological distributions of temperature and salinity, are rare and at the moment the limitations of regional models for the simulation of the behaivour of the hydrography in North Sea and Baltic Sea on longer time scales, up to decades, are not well known. For validation and initialization purposes of a 3-d coupled ice-ocean model about 2.6 million individual temperature measurements and about 2.5 million individual salinity measurements from various databases (ICES, DOD) were used to compile a gridded dataset of climatological monthly 3-d temperature and salinity distributions in the North Sea and the Baltic Sea. This dataset was used to initialize a several years model run. Monthly means of simulated temperature and salinity distributions were compared to the climatological monthly mean data and calculated trends in temperature and salinity for the simulation period will be estimated and compared to observed trends in temperature and salinity during the simulation period.

VARIABILITY OF THE NORTH SEA INFERRED FROM AN ISOPYCNAL OCEAN CIRCULATION MODEL

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The variability of the North Sea is investigated with a regional version of the General Circulation Model OPYC. The regional OPYC model is forced with data from the ECMWF reanlysis in the period 1979 to 1993. The work is focused on two time-scales. The weekly to season time-scale and the season to decade time-scale. The sea level elevation, the sea surface circulation, the sea surface temperature and the sea surface salinity are analysed with the help of statistical tools as Empirical Orthogonal Functions, Associated Patterns, Canonical Correlation Analysis.

HYDRODYNAMICALLY DOMINATED SEDIMENTARY PROCESSES AND FATE OF CHERNOBYL RADIONUCLIDES IN BLACK SEA AND LAKE KINNERET

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We report here investigations of the energy-and-mass exchange processes that determine propagation of pollution in the bottom boundary layer of the Black Sea and Lake Kinneret. Special emphasis has been put on possible propagation of Chernobyl radioactive substances via physical mechanisms such as the global circulation, near-bottom gravity and turbidity currents, internal waves, large-scale eddies and chemical processes in near-bottom layer. One of the key problems in this program has been the modeling of mechanisms of the backward transport of radionuclides during bottom storms from deep water regions toward the beaches and surf zone of the Black Sea and Lake Kinneret. We have investigated the near-bottom density and turbidity current diagnostics and calculation methods for the forecast of these flows on radionuclide transport. Such currents may be catastrophically powerful and may contaminant surrounding waters over tens of meters above the bottom level. The elaboration of current structure diagnostic methods based on the results of spectra analysis of suspended particle size and of current parameter distributions measurements have been performed both in depth and in time. The experimental base will allow development of diagnostic methods and mathematical models which will then be combined into a general model of the Chernobyl radionuclide fate in the Black Sea and Lake Kinneret sediments.

SYNOPTIC UPWELLING NEAR THE CRIMEAN COAST OF THE BLACK SEA

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The southern Crimean coast along the northern Black Sea is an area of frequent synoptic upwelling. Upwelling occurs after a north-west wind event of typically 1 to 3 days. Analysis of AVHRR imagery suggests a variety of scenarios for the evolution of the upwelled water. Sometimes the cold, upwelled water propagates north-westward along the coast. At other times upwelled water detaches from the coast and then propagates along the onshore edge of the Rim Current. The third possibility is the formation of small eddies of upwelled water which slowly propagate offshore before interacting with the Rim Current. An observational program consisting of repeated hydrographic surveys, satellite imagery, and a small moored array with current meters is used to describe two upwelling events which occurred over three weeks in the summer of 1996. In both cases, some of the upwelled water propagated to the Northwest along the coast. However, narrow (5-10 km) filaments of upwelled water also passed directly offshore in each case. The upwelling response was stronger for the first wind event than for the second one, even though the latter event had an apparently larger and more sustained alongshelf wind stress. Observations and simple numerical simulations suggest that initially, local wind stress results in localized upwelling over a variable alongshelf distance. The exact position of the initial upwelling region appears to depend on the position of the Rim Current as well as the influence of possible baroclinic wave motions over the shelf. After the initial development, most of the dense water translates to the Northwest along the coast at speeds of 10 to 20 cm/s. During this phase, offshore directed filaments is developed which carry upwelled water into the Rim Current on time scales of a few days. Finally, the upwelled water has been carried out of the region or sufficiently warmed such that the surface mixed layer returns to a condition with relatively uniform temperature. The alongshelf currents in the region are predominantly barotropic and may result from the radiation of shelf waves by the Rim Current, because of the correlation between oscillations of the Rim Current front and alongshore velocity from the moorings. These shelf waves may explain why the weaker wind event (with the shallow thermocline) led to a strong upwelling response while a stronger wind event (with a deep thermocline) led to a weaker upwelling response.

ASSIMILATION OF ALTIMETER DATA INTO THE BLACK SEA CIRCULATION MODEL

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The TOPEX/POSEIDON and ERS-1 altimeter data for a period from 1992 to 996 are assimilated into the Black Sea primitive equation model. The model uses the sea surface height formulation which substantially simplifies the assimilation procedure.

An objectively mapped difference between altimetric and model sea levels is converted into subsurface anomaly of salinity by the use of surface to subsurface statistics.

The results of altimetric data assimilation experiments are compared with hydrographic observations obtained in the framework of the CoMSBlack (92-95) Programs. An analysis of the results has shown a quite good performance of the assimilation scheme in reconstructing large and meso-scale features of the Black Sea circulation.

An analysis of seasonal variability over the period from 1992 to 1996 based on the altimeter data assimilation runs indicates strong intensification of the Rim Current in winter and spring and reduction of eddy activity in these seasons.

VENTILATION OF UPPER DEEP LAYERS OF THE BALTIC SEA

by Tarmo Kouts (Estonian National Maritime Board)

The vertical circulation in the deeper parts of the Baltic Sea is due to inflows from the Kattegat through shallow sill areas, the Belt Sea and the Sound. The inflows are mainly barotropic and highly variable in time. Also due to mixing in the entrance area the range over which the salinity varies, in the inflow water, varies greatly (Stigebrandt,1987 and Kouts and Omstedt,1993). For the ventilation of the deep layers in the Baltic Sea the main research has been concentrated on studies of major inflows, eg. Fonselius(1969) and Matthaus and Franck(1992). The major inflows are rather rare in time, probably once a decade, but still important ventilating the lower deep layers of the Baltic Sea basins. Another mechanism, less studied, is the ventilation of the upper deep layers, vertically the halocline depth or just below. Based on model calculations, Stigebrandt(1987), showed that most of inflowing into the Baltic Proper saline waters were interleaved just below the halocline to a depth of about 135 m and that the transient time of this water was about 3 year. The ventilation of these layers are more frequent and could probably ventilate the upper deep layer every year, however basic questions on how frequent?, how much water? and what is the origin of the inflowing water? are questions that needs to be answered before we understand how halocline ventilation in the Baltic Proper. The purpose with the present paper is therefore to focus on the ventilation of the upper deep layers in the Baltic Proper and from observations evidence examine this process on basis of high resolution CTD data from Gotland Basin and historical time series of sality and temperature at monitoring stations over several decades. It is concluded that mesoscale and sub-mesoscale processes (lenses, coastal jets, etc.) at the depth of halocline are main driving the ventilation of halocline in the Baltic Proper.

SUB-INERTIAL CURRENTS IN THE IRBE STRAIT AND THEIR CONTRIBUTION TO THE WATER EXCHANGE

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The regular flow pattern in the Irbe Strait consists of an outflow of the less saline Gulf of Riga water near the northern coast in the upper layer and of an inflow of the saline Baltic Proper water along the southern slope. This flow pattern, considered as a typical estuarine flow, is driven by the horizontal pressure gradients. Intermittent wind forcing causes an oscillating character of the flow. Spectral analysis of time series of currents revealed the energy peaks in semi-diurnal, diurnal and synoptic frequency bands. Intensive 10-days measurements of the hydrophysical fields in June 1995 showed that the most energetic are diurnal and low-frequency ($T \approx 48$ h) oscillations explaining 36% and 37% of the total variance of currents, respectively. Only about 8% of energy belongs to the semi-diurnal band. The current fluctuations with the diurnal period can be considered as the system Irbe Strait/Gulf of Riga eigen-oscillations. The low-frequency current was forced by the fluctuating wind causing the sea-level oscillations with the period of 48 hours. The average measured low-frequency flow coincided well with the "geostrophically controlled" Toulany and Carrett model flow in the strait. Despite the large amplitudes of the wind-driven current fluctuations the fluctuating components of the current do not contribute much to the water exchange.

OCEAN CIRCULATION IN VESTFJORDEN

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This report is presented at the conclusion of activities at the Norwegian Meteorological Institute (DNMI) related to two of the NATO MILOC Rocky Road campaigns in Vestfjorden. The operational ocean model at DNMI, ECOM 3d/POM, has recently been improved. Also, work has been undertaken to improve the quality of model forcing. Here, the new model version is validated using the Rocky Road data for salinity and temperature.

Model validation is performed using salinity and temperature profiles of overall means and rms-errors, and statistically interpolated fields at selected depths. The profiles suggest that the model does not reproduce internal motion in a realistic manner. The interpolated fields contain more valuable information for validation purposes. This information includes lateral distribution of salt and heat, as well as the presence and intensity of fronts, meanders, filaments and eddies. Near-surface fields seem to be contaminated by the quality of heat and salt forcing (radiation/SST and river fluxes, respectively). Results from intermediate levels (100 m) are more promising. In the 4 km resolution case, strong fronts may be formed, but instabilities do not develop. However, using a resolution of 1 km the front is broken into eddies. In this case, the mesoscale activity is similar to that of the observational fields. Finally, the barotropic tide is simulated credibly, but the intensity of internal tides appears to be too weak in the model results.

ON THE WATER AND ENERGY BALANCE OF THE BALTIC SEA

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Understanding the role of the Baltic Sea in energy and water cycles requires models for the relevant transport processes. Models must be capable of accurately representing the response of currents and sea level to direct forcing by the wind, and by wind-induced changes of sea level in the Kattegat leading to exchange flows through the Danish Straits. The models must further describe the response of the circulation to forcing by river runoff, precipitation/evaporation and by melting/freezing, with specific emphasis on freshwater budget and thermohaline circulation. A coupled ice-ocean model is utilized to investigate the water, salt and heat budget of the Baltic Sea. Several years has been simulated to investigate barotropic and baroclinic transports of heat and materia within the Baltic Sea and with the North Sea. Additionally, estimations of the fresh water budget with respect to the rates of precipitation, evaporation and river runoff are presented.

HYDROGRAPHY OF THE GULF OF RIGA AND WATER EXCHANGE PROPERTIES IN THE CONNECTING STRAITS, OBSERVATIONS 1993-95

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The general hydrography of a semi-enclosed basin of the Baltic Sea - the Gulf of Riga (total volume of 410 km^3 and a maximum depth of 60 metres) is described on the basis of the observational results from 1993 to 1995. The cyclonic circulation scheme is prevailing in the gulf, but its alteration during the summer months was detected: the currents transported the riverine water and the gulf intermediate water along the western coast into the nutrient-depleted near-surface layer of the Irbe Strait. The different flow regimes depending on the geometry of the straits are found to prevail in the two connections to the Baltic Proper - the Väinameri (sill depth 5 metres, width at the narrowest region - the Suur Strait - 8 km) in the north and the Irbe Strait (sill depth 25 metres, width 30 km) in the west. The observed pure inflows or outflows (current speed up to 1 $m\ s^{-1}$) through the Suur Strait are driven by the direct wind forcing in an association with the sea level elevations. The barotropic inflow and outflow situations can appear in accordance with the changing forcing, but an estuarine-like circulation scheme - outflow in the northern part and inflow along the southern slope of the strait - prevailed on average in the Irbe Strait. This flow pattern is driven by the horizontal pressure gradients between the basins and could be the main mechanism maintaining the observed relatively stable long-term mean salinity (density) difference between the Gulf of Riga and the open Baltic.

SEMIDIURNAL INTERNAL WAVES IN THE STRAIT OF GIBRALTAR

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The Straitof Gibraltar provides extraordinary conditions for the generation ofstrongtidal internalwaves. Tidal flow through the channel generates internal tides on the sloping bottom. Internalwaveswerestudiedon the basis of mooredcurrent and temperature measurements in thewesterngorge of the Strait. The measured doubleamplitudesofthewaves exceed 200 m overthedepthof the ocean about 320 m. The wavespropagateto the west with a wavelength of 50 km. The amplitudes are quasi-stationary. Strongnon-linearity of the waves is observed. Calculations ofthegenerationand propagationof thewavescarried out using a numerical model agree with the measurements.

DYNAMICS OF THE MISSISSIPPI-ATCHAFALAYA COASTAL PLUME

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A series of 5 cruises of 7 days duration was run in 1992-1994 with the objective of characterizing the velocity and salinity-temperature-density structure of the coastal plume of the Atchafalaya and Mississippi Rivers that extends westward over 500 km into Texas and Mexico. During the three downcoast regime cruises (spring-summer-fall) an integral form of the longshore momentum balance shows that a reasonably linear relationship exists between transport of the coastal plume at each section and the local wind stress. This supports the operation of a simple frictional balance of wind stress and linear friction over time scales of several days-to-a-week. At zero wind stress the transport is not significantly different from zero, suggesting the lack of importance of buoyancy forcing in the MACP. Similar analysis for the two summer upcoast observations indicates an entirely different result, i.e, the sectional transports are quite unrelated to local wind stress. Coherence analyses showed that during the winter downcoast regime, current fluctuations are controlled by the alongshore wind stress and, secondarily, off central Texas by the longshore surface slope. During the summer upcoast flow regime variance in the currents in central Texas and central Louisiana in summer is highly coherent with sea level gradients associated with large coastal curvature in central Texas. The observed variability in the current in successfully simulated with a simple model of the along plume momentum balance, as in Lentz (1995). Results provide convincing evidence that major fluctuations of 2-to-7-day time scales, and 20-60 cm/sec range are directly wind driven.

AN UPPER LAYER TEMPERATURE FORECAST IN THE BAY OF BISCAY

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The «Centre Militaire d'Océanographie» is building a three day forecast system of the upper layer thermal structure in the Bay of Biscay. It is based on the coupling of a one-dimensional thermocline model (local turbulent closure scheme [Gaspar & al.,1990]) with an internal tide model [Mazé & al.,1987]. Some modifications have been implemented to make these models more efficient and operational (bottom friction, two layer-fluid).

The coupling can be described as follows : first, the three-dimensional thermal structure is reduced into a two-layer one. The internal tide model is then applied and gives the characteristics of the internal motion. From this, a Richardson number is calculated and converted into a vertical mixing number [Rodi,1993] which is used by the thermocline model. The thermocline model is then applied to produce the temperature profile for the next step.

From a qualitative point of view, the famous cold spots on the continental shelf edge and the Ushant thermal front are well modeled. From a quantitative point of view, the period from june to october of 1994 has been simulated with surface forcing by analysed atmospheric fluxes. In spite of a few restrictions, the results are in good agreement with the measurements of the MINT94 cruise [Pichon,1995], AVHRR images and analysed situations.

INTEGRAL MODEL FOR VOLUME TRANSPORT THROUGH THE STRAITS OF THE GULF OF RIGA

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The Gulf of Riga is a semi-enclosed water-basin connected with the Baltic Sea by two major straits: the Irben Strait in the west and the Suur Strait in the north. The northern outlet itself forms a basin (Väinameri) with three straits. Therefore direct water exchange measurements are very labour-consuming and estimates based on salt-budget method do not characterize distribution between the different straits. Two model versions for volume transport have been worked out on the basis of extensive field measurements during 1993-97. One describing the Gulf of Riga as a two-channel system, and the second as a four-channel-two-basin system. Both models are based on motion equations in the straits and on water balance equations of the basins.. We use HIRLAM wind data, sea level data outside the Gulf and data for river inflows into the Gulf. Sea levels in the basins and flows in the straits are calculated The model behaviour is analysed in stationary and non-stationary boundary conditions. Models are calibrated and verified against 3-months field data and water flows for longer periods are calculated. It appeared, that the straits function together, and even the smallest channel has its own role in the system. The water exchange is much stronger than it would be have been in case of only one channel-system (i.e, the Irben Strait, as usually considered in some models).

NUMERICAL INVESTIGATIONS OF THE EFFECTS OF TOPOGRAPHY ON THE TIDAL CURRENTS CIRCULATION

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A depth averaged numerical model is used to study the tidal currents and the residual circulation in the English Channel. In this numerical investigation the model uses a finer numerical grid to give the detailed spatial structure of the tidal currents under the influence of the local topography, and interaction with other flows in the region. The water motion is supposed to be non-linear and strongly influenced by the topography. We seek to examin the influence of the model boundaries on the computed tidal currents and consider our numerical simulation as a firts step towards the understanding and modeling the physical and ecological conditions of the Eastern Channel. Our work has several objectives. We verify a finer mesh 2D numerical model and to investigate the hydrodynamic behavior of tidal circulation in the domain. We also examin the detailed residual flow pattern in order to give an objective estimate of the minimum Chézy coefficient, required when studying the subtidal precesses. The residual circulation, given by the model with refined grid sizes, apprears to be sensitive to the sea bottom morphology and reveals a central gyre. This gyre, identified also by the measurements, is responsible for the residual flow asymetry, where the transport is more intense near the Straits of Dover.

A NUMERICAL 3D SIMULATION OF THE ANNUAL CYCLE OF THE GULF OF RIGA THERMOHALINE FIELDS

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A free surface version of the 3D GFDL Brian-Cox model was used to simulate evolution of the Gulf of Riga thermohaline fields in 1993-94. The model was modified by including the vertical mixing of Pacanowski and Philander (1981), the dense water overflow and ice cover formation depending on the sea water freezing temperature. The model forcing factors comprised the temporally varying winds, heat flux and the river inflow. The model results are close to the measured vertical temperature and salinity structure of the central Gulf of Riga. The following key processes controlling the evolution of the thermohaline fields in the Gulf of Riga were identified. The vertical thermal structure evolved in response to the air-sea heat exchange. The positive heat flux was responsible for the thermocline development, destroyed by the convection during atmospheric cooling. Strong wind events caused the thermocline erosion followed by thermal re-stratification for calm periods. The vertical haline structure developed in response to the monthly river inflow variations and the water exchange between the Gulf of Riga and the Baltic Proper. Strong saline water inflow events occurred in response to the persistent southerly winds. Short-term wind variability generated the water mass back-and-forth oscillations in the strait between the Gulf of Riga and the Baltic Proper together with the enhanced mixing.

WIND INDUCED CURRENTS IN THE ADRIATIC SEA

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Oceanographic (currents, sea temperature, salinity) and meteorological (air temperature, air pressure, humidity) parameters were measured at two locations in the northern Adriatic in the period from 1978 to 1986. Several episodes with strong wind were selected from the whole data set and classified according to season. Effect of seasonal variability of hydrographic parameters on the wind induced currents was analysed.
Beside time series analysis, wind induced currents were also simulated by nonlinear three-dimensional hydrodynamic numerical model in the characteristic seasonal density fields. Generating forces in the numerical simulations, beside wind, were heat and water fluxes.
Empirical data and the results of numerical simulations, show the existence of strong currents above seasonal thermocline.

ON GENERATION OF NEAR SURFACE EDDIES OVER THE SLOPING BOTTOM

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We consider the quasigeostrophic eddies in a two-layer ocean over the sloping bottom. The dynamics of these eddies is strongly different from both the case of two-layer fluid on the beta-plane and the case of barotropic ocean over the bottom slope. The first important distinction is the existence of steady states with finite energy and enstrophy confined to the upper layer. The streamlines and the potential vorticity isolines coincide in this state. The second distinction is related to the properties of linear waves which have a zero upper layer potential vorticity. The radiation of such waves results in that any initial state with non-zero upper layer potential vorticity (for example confined to the lower layer) does not disperse with increasing time but tends to the steady upper layer state described above plus a dispersing wave field tending to zero at a fixed point. One can readily determine the final steady state and the total energy of radiated waves. This enables to estimate the energy of radiated sub- inertial topographic oscillations when interacting a mesoscale eddy with shelf topography.

HYDROGRAPHIC FINE-SCALE VARIABILITY IN THE BORNHOLM BASIN OF THE BALTIC SEA IN WINTER

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Intensive hydrographic fine-scale variability in the horizontal distribution of temperature and salinity above the permanent halocline in the wintry Bornholm Basin was detected during the expedition RV PLANET 1/97 from January 20 to 29, 1997. The fine-scale measurements were carried out with the so-called CTD chain developed at the FWG and designed to resolve hydrographic variability in the upper layer of the ocean nearly synoptically. 79 CTD sensors were used during this study. While the vertical resolution of the CTD chain was reduced to spatial scales of the order of 1 m CTD profiles were measured every few meters from just below the sea surface down to about 60 m. Current measurements were performed continuously by a shipboard ADCP (300 kHz) and dissipation measurements of turbulent kinetic energy were surveyed with the so-called MICSOS profiler (Meerestechnik Elektronik G.m.b.H., Germany) at selected positions during the cruise. The results presented here will emphasize the role of frontal dynamics and thermal convection in generating the hydrographic fine-scale variability observed in the upper 50 m of the water column in the Bornholm Basin in winter 1997. Dissipation measurements are shown and compared with turbulence approximations based on the Richardson approach.

Generation of baroclinic tides in the Kattegat - observations and modelling.

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The Kattegat is a part of the transition region between the low-saline Baltic Sea and the North Sea, dominated by water of oceanic origin. The mixing between the low-saline surface water and the high-saline deep water in the Kattegat is of great importance for the salinity of the deep water entering the Baltic and thus a key process in the modelling of the Baltic sea. Part of this mixing is due to internal waves generated by the interaction between the barotropic tide and mesoscale topographic features. To study this, the velocity and the density fields have been investigated with high spatial and time resolution at the site of a smal-scale depth in the northern Kattegat (the Alkor Tiefe). The horizontal scale is of the order 1 km and the depth is 140 m, compared to about 80 m which is found in the surroundings. Two field experiments were performed, one during a period with weak stratification and one during a period with a strong two-layer stratification (the usual case in the Kattegat). Each observation was carried during about 4 days with the use of 4 bottom mounted profiling Doppler current meters recording at 5 minutes intervals and with a vertical resolution of 4 m. The ship was continuously surveying the area by means of ship-born ADCP and CTD casts. The observed velocity and density fields indicate a strong generation of baroclinic tides in the area. This is confirmed by a numerical simulation. The efficiency of the transformation of energy into the baroclinic tide i related to the stratification. See also the poster presentation: "High-resolution observations of currents and hydrography in the Kattegat" by Ulf Cederl÷f, Bengt Liljebladh and Johan Rodhe, where other features of the velocity and hydrographic fields are analysed.

PARTICLE TRANSPORT SIMULATIONS IN COASTAL AREAS OF THE GERMAN BIGHT

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The flux of substances between land and ocean takes place in a narrow coastal zone. Though studies on budgets are numerous it remains unclear under which conditions wadden areas and estuaries store marine material or supply the marine environment with terrestrial substances.
By means of a Lagrangian transport model, residuals of the transport of water masses and conservative substances can be determined separately. The model is applied to a tidal estuary, the River Elbe, and a wadden area, the tidal basin in the back of the island of Spiekeroog. Under specified conditions for wind and tidal elevation the accumulation of material, e.g. in as well as upstream of the turbidity zone of the River Elbe, could be simulated and exchange rates be determined. However, the obtained values are valid only for time scales from days to weeks and do not allow to evaluate mean values on larger scales.

NUMERICAL SIMULATIONS OF THE SURFACE AND INTERNAL TIDES IN THE STRAIT OF GIBRALTAR

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New hydrostatic, barotropic and two-layer, high-resolution, boundary-fitted coordinate models are employed for the simulation of the M_2 and S_2 surface and internal tides in the Strait of Gibraltar. While the barotropic model is forced only by imposing observed M_2 and S_2 tidal surface elevations at the open boundaries, in the two-layer model observed mean surface and interface positions at the open boundaries are also imposed. The models are validated by comparing simulated tidal surface elevations and tidal velocities with observational data. A comparison between the fields of tidal surface elevation derived from the two models shows that significant differences occur in the region of the Camarinal Sill, where the two-layer model predicts a time dependent hydraulic control which constrains the exchange flow between the North Atlantic and the Mediterranean Sea. The two-layer model is also capable of describing eastward propagating internal bores generated by the interaction of the tidal flow with the Camarinal Sill. Forms and positions of these internal bores are compared with those inferred from the analysis of synthetic aperture radar images acquired by the European Remote Sensing satellites.

BUOYANT EKMAN LAYERS OVER VARIABLE TOPOGRAPHY

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Numerical simulations of the turbulent bottom boundary layer at the coastal area off Cape Hatteras, U.S.A., are made using a two-dimensional bottom boundary layer model. Two cases of interior current are considered: a) a constant and b) a time dependent along-the-isobaths interior current. Density gradience across a sloping boundary gives rise to buoyancy forces which oppose the Ekman flow imposed by the interior current. The buoyant inhibition of the Ekman flow in the presence of topographic effects approximating the continental shelf and slope, is addressed. The turbulent "shut-down" of the Ekman flow on the slope is faster than that on the shelf causing horizontal convergences or divergences depending on the direction of the interior current. The subsequent vertical motion advectively drives boundary layer fluid outwards and into the interior or downwards into the boundary layer from the interior. In the constant interior case, tracer input simulations show the boundary flow separation at the continental break reaching up to 40 m above the bottom. In the time dependent interior case, mixing and restratification of the boundary layer alternate during a cycle, while the lateral variability of the Ekman transport leads to a net displacement of the boundary layer fluid across the bottom.

INTERNAL WAVES IN COASTAL WATERS

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Internal waves play an important role in coastal zone hydrodynamics.They perform the function of ventilation of the sea, as well as interactions with the seabed, transport of sediments and creation of seabed topography. One specific feature of shallow-water internal waves is a predominance of the nonlinearity that leads to intensification mixing processes. On the basis of our experience with long-term observations and thorough study of published data, we present a review of modern-day knowledge of internal waves in the shelf and coastal zone. The principal processes leading to the generation of intense internal waves are described. Important features of shallow-water internal waves, such as effects of nonlinearity and the soliton-like character of the waves, are discussed. Special attention is devoted to factual data for internal wave parameters measured in different coastal zones of the World Ocean. On the basis of this analysis, coastal zones with large-amplitude internal waves are presented.

OA5

SEASONAL EVOLUTION OF WATER MASS STRUCTURE AND SHELF-SLOPE EXCHANGES AT THE IBERIAN SHELF (NW MEDITERRANEAN). PRELIMINARY RESULTS OF FANS CRUISES

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Three oceanographic cruises were carried on the Iberian shelf and slope at different seasons: autumn, winter and early summer, last year. An area of about 7500 km^2 was covered in each cruise with an average of 140 CTD casts and surface TS analysis and ADCP measurements underway. The results presented here concerned the patterns of distribution of the continental influenced waters over the shelf, shelf-slope exchanges and interaction with the main current, at the shelf break. This preliminary results show permanent features, like the anticyclonic circulation over the shelf or the locations where shelf-slope exchanges are more intense. Other features, like water masses characteristics or intensity of the shelf break current, show a clear seasonal trend, at different stratification conditions and also with markedly differences on outflows from the Ebro river.

REMOTE SENSING OF THE LAKE BAIKAL THERMAL FRONTS

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Different mesoscale features known for lakes, coastal and open seas are typical for the Baikal due to Lake great dimensions. NOAA AVHRR IR 1994-1997 HRPT imagery archive was analysed for thermal fronts detection and its variability studies with special emphasis on those patterns, which can correlate with deep convection. Thermal front known as thermobar divides waters with temperature below and upper then temperature of maximal density. Typical for temporal lakes shallow spring and autumn thermobars generation was studied for selected areas of the Lake. Specific for the Baikal due to its depth and steep slope deep water thermobar can be produced due to coastal heating (spring) and cooling (autumn) or due to riverine water influence. Deep convection patterns were observed along such thermal front interface. River plume can also be an area of deep "cascading" along the slope associated with difference in mineralisation between river and lake waters. Cold "spots" produces by bottom waters on the surface in frontal areas can be detected as indicators of deep mixing features. Selenga river thermal fronts seasonal evolution analysis along the section demonstrates transition "shelf-open lake" zone evolution. Cyclonic eddies and circulation cells can determine a "chimney" patterns of deep mixing during spring and autumn homothermy. Estimations of advection fields were derived by sequential surface temperature fields using regression solution of inverse heat transport problem.

NUMERICAL STUDY OF THE WIND-DRIVEN CIRCULATION IN THE MEXICAN PACIFIC NEAR-SHORE ZONE

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Multilevel numerical model of the Marine Hydrophysical Institute (Sevastopol, Ukraine) based on the primitive equations of hydrodynamics with the horizontal resolution of 9x9 km and real bottom relief and orography has been used for studying the water dynamics generated by the winds in the Mexican Pacific near-shore zone (107-102^{0}W and 18-24^0). A series of numerical experiments aimed at describing three-dimensional circulation in this area has been carried out. The processes of development and transformation of the upwellings/downwellings being of a special interest. At the initial moment the temperature and salinity were taken horizontally homogeneous and vertically stratified with the profiles corresponding to those observed in spring. The dominant winds in this period are the north-eastern ones, but the experiments were undertaken with the winds of 8 directions. The favourable winds as well as the areas of the most intensive development of the upwelling processes were established for the Mexican Pacific near-shore zone.

PECULIARITIES OF FLOW DYNAMICS IN THE CANARY CURRENT UPWELLING

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This report will address renewal results of the combined studies of ocean dynamics near a shore of the North-Western Africa. Topics to be covered include problems of coastal, shelf and continental slope circulations. Observations were made from space satellites in visible and infrared ranges and from a board of research vessels (conductivity-temperature-depth, sea surface temperature, acoustic Doppler current profiler and sonar measurements). Data under analysis were collected during the past decade. Special interest focuses on quasi-geostrophic along shore current and vortexes as well as on system of cross-frontal flows and subsurface lenses in the main upwelling front area. Field of discussion will also concentrate on influence of the local bottom topography on upwelling dynamics.

Dynamics of baroclinic mesoscale eddies at the outer shelf

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Dynamics of near-bottom mesoscale eddies over the slope is modelled numerically. The numerical model is mainly the same as used by Shapiro and Hill (JPO, 1997) to simulate dense water cascades over the shelf break. Four idealised major bottom topography patterns were considered: constant slope, shelf break , slope with a canyon, and slope with a spur. If was found that an eddy over the constant slope moves mainly along isobaths generating a downslope water cascade in the bottom boundary layer. The eddy could split into parts at the shelf break Various dynamical pattern were identified over canyons and spurs depending on the parameters of the eddy and bottom topography. This includes transformation of the eddy into an arrested current at the bottom of the canyon and strong relative current intensification at the head of the eddy after its passage over the spur.

OBSERVATIONS AND MODELLING OF AN EVOLVING INTERNAL BORE DURING SESAME 1996

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Observations of internal waves were made at the Malin shelf edge during SESAME (Shelf Edge Studies Acoustic Measurement Experiment), in conjunction with SES, in August-September 1996. These measurements provide a unique high resolution dataset demonstrating internal wave generation and propagation. In this note a particular observed example of the evolution of an internal bore is presented. The process is shown clearly in a sequence of thermistor chain tows across the shelf break over a tidal cycle, as the double-sided bore transforms into undulations and eventually into more solitary waveforms. The feature was less well resolved by ship-mounted ADCP, but some current structures were discerned.

From the observations the kinetic and potential energies are derived showing a strong conversion from kinetic energy in the internal bore into potential energy in the evolved internal waves. Further, the bore evolution is then modelled using a KdV finite difference model which predicts the lengthscales of the internal waves, but underpredicts their amplitudes. Results of a numerical simulation of the internal tide in the frame of the rotated-modified extended KDV equation are also presented.

Transport of Fine Suspended Matter on the Shelf by Mesoscale Currents

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A semi-analytical model is developed for simulating the transport of fine suspended particulated matter (SPM) on the shelf by mesoscale currents. The vertical profiles of horizontal velocity and SPM concentration are calculated analytically in a zero order approximation (i.e. neglecting horizontal inhomogenities of the bottom boundary layer). Then these profiles are used to calculate horizontal fluxes for the depth integrated advection-diffusion problem that is solved numerically. The resuspension flux is taken in the form F=M(T-T0) where T =T(x,y,t) is the variable bottom stress, M and T0 are empirical constants. The settling velocity is taken constant. The model was run to simulate SPM transport by various types of mesoscale currents including cyclonic and anticyclonic eddies and a meandering along-shore current. It was found that because of strong non-linearity of the problem a small variability in the current strength result in a great difference in erosion and sedimentation rates at different location beneath and adjacent to the current.

ON THE INFLUENCE OF INTERNAL WAVES PACKETS ON THE VELOCITY STRUCTURE OF SHELF WATERS

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The report presents observations of the velocity and thermohaline structures of internal waves (IW) field carried out in July, 1992 in a frame of joint russian-american oceanic experiment PRE-CHERI (Critical Hydrodynamic, Electromagnetic and Radar Investigations). Data were collected with a vessel-mounted 75-kHz acoustic Doppler current profiler (ADCP) and NB MK3B CTD-unit in areas of the continental shelf and slope near the eastern shore of the North America. During the experiment spectral, temporal and spatial characteristics of tidally generated in the shelf break area packets of IW was studied. As a result of the advanced investigation strategy it was found that IW with a wave length of about several hundreds meters strongly effect on velocity structure of shelf currents at depths from thermocline down to bottom. These measurements have been also incorporated with a satellite mesoscale images in order to characterize shelf dynamics of IW packets.

THE OVERFLOW OF DENMARK STRAIT OVERFLOW WATER IN A NUMERICAL MODEL

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One source contribution to the North Atlantic Deep Water is the Denmark Strait Overflow Water (DSOW) that enters the subpolar gyre between Iceland and Greenland. The southward and downslope spreading of the overflow plume in a bottom intensified current poses a major problem to geopotential-coordinate numerical models. The mixture of horizontal advection and vertical convection in the bottom most layers leads to a strong diffusion of water mass properties that may prevent the model from conserving approximately the bottom water mass characteristics. This in turn prohibits the evolution of a bottom water current on the basin depth. We present first results from a numerical high resolution, z-coordinate model and discuss possibilities for an improved representation of the bottom water characteristics and the downslope advection of the dense water plume.

ON THE COHERENT STRUCTURE OF CURRENTS IN TWO STRAITS OF THE GULF OF RIGA

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Under the multidiscipline study "The Gulf of Riga Project" of the Nordic Council of Ministers the current measurements in Irbe Strait connecting Gulf of Riga with Baltic Proper and in Virtsu Strait connecting the Gulf of Riga with the entrance of the Gulf of Finland in 1993-1995 were carried out. In both straits the current fluctuations with inertial and diurnal periods and with periods of some days were observed, that were mainly interpreted as inertial oscillations, seiches or atmospherically induced and in one case as topographic mode. If in the Virtsu Strait the one-layer structure with current fluctuations in alongstrait component only was observed (Suursaar etc. 1995) then in Irbe Strait more complicated two-layer structure of fluctuating currents was observed. In spite long time series of current measurements in Irbe and Virtsu Straits only during some weeks in 1994 and 1995 simultaneous measurements were carried out. Statistical and spectral characteristics about periods of oscillations, phase shifts, amplitudes allow to speculate why sometimes the oscillations in both straits are coherent and sometimes not. The available data base is not sufficient to argue clearly that coherence of oscillations in two straits of the Gulf of Riga is depending on generating force or on the origin of oscillations.

THE EFFECT OF WATER FORMATION ON THE DISTRIBUTION OF OXYGEN AND NUTRIENTS IN THE NORTHERN AEGEAN SEA

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In the framework of the Open Sea Oceanography Research Program of NCMR, eight oceanographic cruises were performed from August 1986 to August 1989 in the Northern Aegean Sea. Nowadays, the oceanographic research in the area is continued within the frame of the projects INTERREG and MAST III-MATER. In contrast to the low nutrient concentrations observed in the surface waters of the Eastern Mediterranean, the North Aegean Sea has relatively high concentrations in the area influenced by the inflow of Black Sea waters. More importantly, the signal of this surface input (created from both influx of Black Sea waters and the riverine inputs to the coastal areas) can even be traced into the deep sub-basins of the North Aegean Sea. Dense water formed in the shelf areas sinks, transporting organic and inorganic material from the surface to the deeper water layers. The concomitant respiration and decomposition produces nutrients (regenerated) at the expense of oxygen. The concentrations of nutrients observed in the deep layers of some of the deep sub-basins in the North Aegean Sea (NO_3: 3.3 μM, PO_4: 0.15 μM, SiO_4: 7.5 μM) are higher than those generally observed in the Cretan Sea (NO_3 : 2.8 μM, PO_4: 0.1μM, SiO_4: 4.0 μM). It is also interesting to note that the preformed nutrients calculated in the usual manner, give positive values for the deep layers of these sub-basins, while negative values are found for the Levantine and Ionian Seas.

MODEL INTERCOMPARISON STUDY FOR A THREE-DIMENSIONNAL IDEALISED TEST CASE.

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Several coastal ocean models have been used to compute the circulation on the North-west European Continental Shelf. Five of them, developed within the European Union, are compared in the scope of an idealised three-dimensional test case, dealing with the geostrophic adjustment of a freshwater cylinder. As the central eddy adjusts, unstable baroclinic vortices start to grow. All the models are able to produce such unstable vortices. However, two of them produce an order-two instability, which is in accordance with a previous laboratory experiment, while the others exhibit an order-four instability. Using a simple scaling analysis, it is seen that the azimuthal wavenumber depends on the ratio of the kinetic energy to the available potential energy. It appears that the discrepancy in the azimuthal wavenumber is mainly due to the effect of the discretisation of the horizontal advection of momentum which could produce a significant decrease of the total kinetic energy.

NUMERICAL SIMULATION OF THE INTERNAL TIDE EVOLUTION ON THE NORTH-WEST SHELF OF AUSTRALIA

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A numerical solution to the generalised Korteweg - de Vries (gK-dV) equation is used to model the evolution of an initially sinusoidal long internal wave, representing an internal tide. The gK-dV equation includes quadratic and cubic nonlinearity, the Earth's rotation, dissipation in the bottom boundary layer, and horizontal variability of density stratification and depth. The coefficients of this equation are calculated using observed conditions for the North-West Shelf of Australia. It is shown that the Earth's rotation is important for modelling of the internal tide on the NWS. Results of the numerical simulations are compared with observations of the internal wave field on the NWS which show many of the features produced by the gK-dV equation.

TIDAL DYNAMICS OF THE NORTHERN ADRIATIC SEA. COMPARISON OF MEASUREMENTS AND MODEL RESULTS IN THE GULF OF TRIESTE.

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Tides in the Northern Adriatic Sea were examined using the 2D finite difference model (TRIM - Tidal, Residual, Intertidal Mudflat by Casulli).
The tuning of the model consisted in searching, for the seven main constituents, the better open boundary tide phase conditions expressed as a third degree polynomial of the spatial coordinate on the open boundary itself. The comparison between observed and model level was made at four ports within the model domain. The RMS modulus of the vectorial difference was less then 1.3 cm at Trieste.
The main characteristics of the tide in the Northern Adriatic Sea revealed by the model are shown with particular regard to the Gulf of Trieste. Here the comparison between the model values and the experimental results in winter 1984-85 and spring 1985, shows a good agreement.

BLACK SEA COASTAL ZONE DYNAMICS BY SATELLITE REMOTE SENSING DATA

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By using of potential of merging satellite remote sensing data in optical range Landsat MSS and TM as well as radar data provided by SAR ERS-1 satellites together "in situ " data are identified and mapping sea coastal zone spatio-temporal changes. A methodological procedure assisted by different algorithms and models was applied to satellite data.
Monitoring of Black Sea and Danube Delta coastal zone dynamics is an essential task to establish an integrated multipurpose program for managing Romanian Black Sea coastal zones.

THE STOLPE CHANNEL OVERFLOW IN THE BALTIC SEA: THE OBSERVATIONS AND MODELLING

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We examine a number of closely spaced CTD transects across the Stolpe Channel, measured under different weather conditions, to investigate the variability of the thermohaline structure of overflow water. When the wind, regardless of its direction, is weak, moderate, or fresh, the transects show a fan-like divergence of isopycnals approaching the southern slope of the channel, and a displacement of the densest water toward the northern slope. Under gale winds from the west-south-west, this observed divergence disappeared. We speculate that these features result from a double-cell circulation across the channel induced by Ekman transport at a sloping boundary and that they occur when the overflow water is moving east while the flow in the upper layer has the opposite direction. To verify our speculations, a 3D numerical model simulating the wind-driven circulation in the Stolpe Channel has been developed using the well-known Princeton code (Mellor, 1993). When a gale wind from the east is applied to computational domain, the model generates the fan-like structure of isopycnals in the channel except its western part, just in accordance with the observations. When we switch off the bottom friction, the fan-like structure is not produced. This make us confident that the observed structure of overflow water in the Stolpe Channel is controlled by Ekman transport at sloping sea bottom.

OA6 Dynamics of the polar ocean and its coupling to sea ice

Convener: Willmott, A.J.
Co-Convener: Lemke, P.

SPECIALITIES OF THE FLEXURAL-GRAVITY WAVE PROPAGATION THROUGH THE RUPTURE IN THE ICE FIELD

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The effect of the rupture in the ice field on the propagation of surface waves in a basin of finite depth is considered. The dependence of amplitudes of the wave disturbances formed in front of the rupture and behind it on the period of wave running onto the rupture, ice cover characteristics and basin's depth is investigated. The structural features of the ice bend are showed for different boundary-contact conditions at the rupture modelling the crack in ice or overlaying of the ice floes. It is shown that the waves of small periods pass through the floes' overlaying more effectively than through the crack between them. However, there appears the opposite phenomenon within the mean period range.

The ice compression introduces not only quantitative but also qualitative corrections into the distribution of the amplitude coefficients over the period of incident wave. When the compressing forces are absent, satisfaction of the floes' overlaying condition makes the full transmission of the waves of short periods impossible despite the propability of such a phenomenon under condition of the crack. In addition, when the ice has different thicknesses on both sides of its mentioned non-uniformities, the reflection coefficient does not depend on what a side of the floes' contact line the flexural-gravity wave is incident from.

THE BROKEN ICE EFFECT ON THE PROPAGATION OF SURFACE WAVES OF FINITE AMPLITUDE

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The influence of broken ice on the traveling periodic surface waves of finite amplitude in the sea of constant finite depth is considered. The uniform asymptotic expansions up to third degree are obtained for the fluid velocity potential and elevation of the basin's surface. Basing on them, an analysis of dependence of the wave disturbances on the ice conditions and characteristics of initial main harmonic is fulfilled. It is shown that non-linearity displays the ice effect even on the long waves. In this connection, such an effect manifests mainly in the phase shift of the wave disturbances, and amplifies with time. Neglect of the non-linearity of vertical acceleration of floating ice floes leads also to the phase lag and weak decrease in the wave amplitude.

Estimated is the contribution appearing in non-linear addenda to the wave disturbances when the horizontal gradient of the first approximation to the basin's surface elevation is taken into account in expression for the velocity horizontal component. It is determined that corrections introduced to the second approximation manifest only via the dynamic boundary condition, at the same time in the third approximation they manifest both via kinematic and dynamic conditions.

An analysis of influence of the ice on the mean non-zero transport of the fluid particles in a non-linear wave is carried out.

SURFACE WAVES RUNNING ONTO THE BOTTOM'S STEP IN THE SEA WITH ICE COVER

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The normal incidence of the surface waves of small amplitude from the deep-water area onto the bottom's step in the sea with floating ice is considered. The wave motion on both sides of the step is assumed to be potential. The nonleaking condition is satisfied at the bottom (behind the step) and at the step's wall. In front of the step, we require the disturbance damping with depth. The equation of the ice plate oscillations is assumed as a boundary condition at the ice-water contact interface.

The problem is reduced to the system of algebraic equations for the amplitudes of transmitted, reflected waves and near-step evanescent eigenmodes. Its numerical realization is carried out in the case of broken ice. The dependence of the amplitude coefficients and phase shifts of reflected and transmitted waves on the ice thickness is studied. The width of zone of manifestations of disturbances caused by evanescent modes is estimated. The ice effect on the disturbance modifications with distance to the step is considered. It is shown that the effect of floating ice on the formed disturbance characteristics appears mainly at the incident wave frequencies whose magnitude degrees are comparable with those of the ice buoyancy frequency. The ice decreases the magnitude of the reflec-

ANNUAL VARIABILITY OF CARBON FLUX IN THE UPPER GREENLAND SEA, AS EVALUATED FROM MEASURED DATA AND A BOX MODEL.

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Measurements of nutrient, oxygen and the carbonate system parameters performed since 1970 have been used to estimate the evolution of the concentration fields over the year in the surface mixed layer (SML) and underlying water in the central Greenland Sea. This, together with synoptic surface wind data from the NCEP/NCAR reanalysis project, is used to evaluate the vertical mixing, the biological production and decay as well as the air-sea exchange of CO_2. In the end of the winter season, the vertical mixing dominates the change of the nutrient concentration in the SML. The mixing factor estimated for this season is used for the whole winter season (sigma < 0.1 between the SML and underlying water) to compute the addition of chemical constituents to the SML from below. The residual nutrient concentration change, after the mixing contribution is subtracted, is attributed biological production or decay. By applying appropriate ratios of nutrients to carbon and oxygen for the biological processes, the apparent concentrations without any air - sea exchange is achieved. The difference between these apparant concentrations and those measured are compared and discussed in relation to the air - sea exchange computed from the wind field and the measured carbonate system. The computations are performed with a one day resolution and the advective contribution is neglected, as the horizontal gradients in the central Greenland Sea gyre are small. This presentation is a contribution within the MAST III project ESOP-2.

PECULIARITIES OF THE ICE DRIFT IN THE ARCTIC BASIN

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Scientific research presented in this work is based on the results of investigations being carried out within the International Arctic Bouy Program - IABP. Data used in this work was obtained from 378 buoys for 1979-1994 period. Based on this data annual and seasonal drifting ice velocity fields were created. Average speed of 0,01 m/s corresponds to the speed of 315 km per year. The highest values (1,45 m/s) were registered in the area of the Greenland Sea, the lowest (7,97x10E-5 m/s) - in the area of Canadian Archipelago. Fields of kinetic energy were mapped for the areas best provided with the data. The highest values (up to 2 m^2/s^2) are found close to the eastern coast of Greenland while throughout the whole basin the values are two orders less (from 0,001 to 0,05 m^2/s^2). Along the axis of the transarctic drift and in the area of cyclonic circulations to the north of Franz Josef Land local maximums of values can be observed. According to these kinetic energy fields it is possible to define 3 regions: northern part of the Greenland Sea, the zone of anticyclonic circulation in the Beaufort Sea and the central part of the basin. The results of the spectral analysis of monthly mean values of kinetic energy for all three regions enable to point out the northern part of the Greenland Sea. Only in this area oscillation was registered with the period of 4-5 years. The region is probably involved in the Northatlantic autooscillation system. In the area of the Beaufort Sea its own oscillation was registered with the 3,2 years period. On the whole the highest values and repeatability of spectral densities are related to the band of frequencies corresponding to the range of periods of 1-1,5 years.

MODELLING OF ATMOSPHERE - SEA ICE INTERACTION IN THE REGION OF MEDIUM-SIZED POLYNYAS

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The nonhydrostatic atmospheric model METRAS is coupled to a new developed mesoscale dynamic-thermodynamic sea ice model. The coupled model can be used on a spatial scale up to 300 km and a time scale up to 1 week. The sea ice model has several ice thickness classes. For calculating the turbulent fluxes over the heterogeneous ice-water-surface a flux averaging method is applied. The modelsystem is used to simulate the flow of cold air over polynyas. It is shown that large turbulent fluxes of heat and momentum over polynyas of diameters up to 100 km cause a very heterogeneous wind field. It is characterized by a large vortex on the downwind side of the polynya. In this area the near surface wind speed is considerably reduced. The position of the polynya changes and due to convergent ice drift its horizontal extension decreases. In consequence of that the wind field is gradually homogenizing. Furthermore the freezing of a polynya is simulated. Even a thin layer of new ice reduces the heat transfer from the ocean into the atmosphere to such a high degree that the vortex on the downwind side disappears and the near surface wind speed increases.

STABILITY OF DARCY CONVECTION IN BRINE WITHIN SEA ICE

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The onset of Darcy convection in a compressible brine saturated sea ice in the presence of temperature and salinity vertical gradients has been investigated. In the definition of the problem the Dufour and Soret effects were taken into account. The critical values of parameters were found by analyzing spectrum of linear convective equations. The limits of monotonic and oscillatory instability domains with respected to longitudinal perturbation has been defined. The brine compressibility has been determined to increase significantly the stability relatively oscillatory perturbations, however it has no influence on the evolution of monotonic ones. Means of the ice critical permeabilities are of two-three orders lower than those obtained in a framework of Boussinesque model. For a special case of brine incompressibility a domain of parameters corresponding to double-diffusive instability in brine was described.

A COMPARISON OF ICE DRIFT SIMULATIONS IN THE GULF OF ST. LAWRENCE USING LAGRANGIAN AND EULERIAN MODELS

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This paper examines the performance of ice drift models using Lagrangian and Eulerian formulations. One model is based on a discrete element approach, which solves the equations of motion for individual ice floes. The ice cover is modelled as an ensemble of random-sized inelastic disks. The second model is based on a Smoothed Particle Hydrodynamics formulation, where the ice cover is represented by an ensemble of discrete particles. The rheology of the ice cover is represented by a Mohr-Coulomb criterion. The Eulerian model is the operational model employed by the Canadian Ice Service and includes a viscous plastic rheology with multiple ice categories. The models are used to simulate ice movements in the Gulf of St. Lawrence. Wind and ice chart data from the spring of 1997 are the primary model input data. The models will be evaluated by comparing the results from a series of simulations to available observations.

Synoptic modelling of winter seaice in the Bellingshausen Sea

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We present results of modelling the seaice response to atmospheric forcing in the Bellingshausen Sea. The period chosen for study was 45 days in July and August 1993. Observations (SSMI) show a rapid retreat, partial readvance and retreat, followed by an advance past the original ice edge. We are interested in how well a standard seaice model (the Alfred-Wegner Institut model; known to reproduce the seasonal cycle well) responds to synoptic forcing. The model is forced with 10m winds and 1.5m temperatures from UKMO and ECMWF analyses; cloud cover and radiation is from climatology. Initial results using the UKMO analyses for forcing were disappointing, with the model showing little of the rapid retreat/advance seen from SSMI. Simplistic calculations assuming ice motion at 2.5% of wind speed indicated that the ice retreat observed was too fast for the winds imposed; the temperatures were too low to allow thermodynamic retreat. We then tried a number of sensitivity experiments using ECMWF forcing, removing thermodynamics, and rescaling the winds for consistency with scatterometer winds. These result in a significant improvement in the simulation and allow us to determine what processes are most important accurately simulating the movement of the ice edge.

SEDIMENT ENTRAINMENT INTO ICE VIA SUSPENDED ICE CRYSTALS

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Sediment transport over large distances is usually a very slow process. However, if sediments are entrained into ice, which is consistent with experimental evidence, they could be transported effectively over large distances. In rivers contaminated sediments could be entrained into the ice during the winter season and transported to the ocean bottom in the spring. There the sediments could be re-entrained into the sea ice the next winter and transported hundreds of kilometers before being released by melting. Sediments from the river outlets in the Kara Sea could be transported to the Svalbard-Greenland area in a few years.

The possibility of sediment entrainment into ice via suspended crystals is studied by means of a numerical model. The model is based upon Reynolds Equations with turbulence-, ice generation - and coagulation-closures chosen to be as standard, simple and robust as possible. It is expected to be most accurate for well mixed flows, which should be most interesting when there are suspended sediments. Since the experimental evidence is weak, the modelling of the ice-sediment coagulation process must necessarily be associated with significant uncertainty. Provided that a coagulation coefficient is reasonably large, the model predicts that the sediment-into-ice entrainment process may be efficient even in wind forced flows.

LARGE SCALE ATLANTIC OCEAN RESPONSE TO HIGH LATITUDE ATMOSPHERIC FORCING IN A COUPLED OCEAN-SEA ICE MODEL

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Variations in high-latitude atmospheric forcing affect the large scale oceanic circulation through modifications of deep water formation in different ways. Here we focus on the role of sea ice and fresh water transports from the Arctic Ocean.
With an oceanic general circulation model of the Atlantic and the Arctic Ocean coupled to a comprehensive sea ice model we conduct a series of numerical experiments that differ in the variability of the surface forcing. We compare results with variable atmospheric forcing over the whole domain with results where the variability is restricted to high latitudes. We identify the spatial as well as the temporal relationship between high latitude events and the response in the mid-latitudes of the North Atlantic.

A NUMERICAL INVESTIGATION OF THE ROSS SEA POLYNYA

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Each spring, a polynya of relatively large size is observed over the continental shelf of the Ross Sea. The ice starts to retreat along the Ross ice shelf at the end of November–beginning of December. The retrait then progresses northwards, producing a wide ice-free bay surrounded by ice. In January, the polynya joins the "outer" ice edge which progresses more classically southwards. Despite the coarse horizontal resolution used (3° × 3°), this feature is well reproduced by the UCL global ice–ocean model which results from the coupling of a free-surface ocean general circulation model with a comprehensive thermodynamic–dynamic sea-ice model. We have taken this opportunity to analyse in detail the mechanisms responsible for the polynya formation in the model. This analysis suggests that the wind-induced ice export out of the Ross Sea continental shelf is the major cause of the polynya opening as well as of the lower ice compactness observed during winter in the polynya sector. The weaker ice divergence (particularly in summer) over the eastern side of the shelf explains why the area remains ice covered all winter long there. Warm water intrusions on the shelf seem also to take an important part in the polynya formation. They limit the ice thickness in winter and induce melting in summer. When their effect is not accounted for, the model is unable to generate a polynya.

INFLUENCE OF SEA-ICE–OCEAN INTERACTIONS ON THE OCEAN GENERAL CIRCULATION

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Sensitivity experiments are conducted with a global ocean–sea-ice model in order to determine to what degree sea-ice–ocean interactions control the circulation of the World Ocean. The model results from the coupling of a free-surface ocean general circulation model with a comprehensive thermodynamic–dynamic sea-ice model. The coupled model has a horizontal resolution of 3° × 3°, and there are 20 vertical levels in the ocean. The forcing consists of surface fluxes of heat, freshwater, and momentum derived from climatological atmospheric data. The sensitivity runs performed with the model suggest that the large-scale ice–ocean interactions have nearly no influence on deep-water formation in the North Atlantic. In the Southern Hemisphere, both the exchanges of heat and freshwater between ice and ocean seem to take an important part in the production of deep water and in the determination of the water-mass properties. The brine release during ice formation over the Antarctic continental shelf increases significantly the salinity there and thus favours the sinking of dense water along the continental slope. In some other regions, as the southwestern Pacific, net ice melting caused by ice convergence forbids deep mixing. The contact with the ice also imposes that surface waters are very close to their freezing point, this property being important for determining the density of the Antarctic Bottom Water.

DYNAMICS OF ATMOSPHERE - SEA ICE INTERACTIONS AT DIFFERENT RESOLUTIONS IN A SIMPLE GCM

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This work uses a "simplified" global circulation model in which a sophisticated dynamical scheme is married to idealized representations of friction, heating and sea ice dynamics. We have implemented a variable horizontal mesh, performed by choosing a high-resolution pole (the South Pole), then applying a conformal transformation to increase the resolution in the area of interest. We present some preliminary results in which we compare simulations with and without this variable grid. These results will focus on feedback between the sea ice cover and individual baroclinic systems.

THE FRESHWATER LAYER IN THE GREENLAND SEA

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The inter - annual distribution of the freshwater layer in the Greenland Sea plays an important role in preconditioning deep convection. The space - time variability of the freshwater layer was determined from salinity measurements of 17 cruises to the Greenland Sea between 1986 and 1997. The 34.65 isohaline was chosen to identify the thickness of the freshwater layer.
The total freshwater content was calculated for a representative box in the central Greenland Sea relative to 34.93 and compared with model estimates of ice flux through Fram Strait.

ATMOSPHERE–SEA ICE–OCEAN FLUXES IN SIMIP RUNS

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The Sea Ice Model Intercomparison Project (SIMIP) is a WCRP/ACSYS project that aims to determine the optimal representation of the sea ice component in coupled climate simulations. A hierarchy of sea ice models of differing complexity are driven with the same forcing and on the same grid. Simulation results (ice thickness, extent, drift, roughness, age) are compared with a standard verification data set based on a large number of observations (ice drift buoys, remote sensing, field measurements). The first stage of SIMIP investigates the effect of sea ice rheology on the state of and the fluxes at the atmosphere–ocean interface, such as net freezing rate, ice-ocean and ice–atmosphere heat fluxes, and surface temperature. Also, differences in the variability of the different models in response to external forcing are studied by the means of empirical orthogonal functions. These results are presented for the model hierarchy, and the significant differences found between the different rheologies are pointed out. Thus, the choice of sea ice rheology which modifies sea ice dynamics is shown to have a considerable impact on the ocean–atmosphere fluxes in climate simulations. A comparison of sea ice drift simulated by the different models with a large number of drift observations obtained from ice buoys and remote sensing shows that an improved viscous-plastic rheology yields the most realistic simulation.

EVIDENCE OF THE COUPLING A HUGE ICE EDDY AND SYNOPTIC VARIABILITY OF ANTARCTIC OCEAN CIRCULATION

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During the last ten days of June 1997 in the Antarctic zone of the Southern Ocean on the border Lasarev and Weddell Seas an interesting phenomenon took place. In according to satellite IR- images from NOAA-12, 14, received at the Russian Antarctic Meteorological Centre "Molodiozchnaja", a huge ice eddy occurred at the edge of the sea ice. The appearance, development and decay of eddy with clockwise rotation and diameter about nine hundred kilometers continued just three days. The potential reasons for a such drastic change in the sea ice cover are discussed. A plausible explanation is the interaction with a water jet of Antarctic Circumpolar Current (ACC). As an indirect indicator of synoptic and meso-scale variability of ACC activity the southward manifestations of the sea ice fringe are used.

Recent variability of Antarctic sea-ice concentration and its physical causes

Abstract submitted to EGS Nice 1998 Session OA6 "Dynamics of the polar ocean and its couplings to sea ice"

Results are presented of hemispheric and regional variations in Antarctic sea-ice concentration, focusing especially on the Weddell, Bellingshausen-Amundsen and Ross Seas' regions, over the whole of the SSM/I passive microwave satellite dataset including the most recent available data (July 1987 into 1997). These data have been derived from raw brightness temperatures using an improved algorithm which has been carefully re-parameterised for seasonal Antarctic conditions and to allow for changing satellite retrieval characteristics. The results of validation against infra-red (AVHRR) and radar altimetry (GEOSAT) data are shown.

Comparison with re-gridded climate reanalyses field data including surface pressure, temperature, wind, precipitation, latent and sensible heat flux and total cloud cover, has revealed the extent of mutual sea-ice/atmosphere couplings. Modified theories, in the light of these findings, regarding (i) the relative importance of thermodynamic and dynamic processes driving sea-ice and (ii) sea-ice/ocean/atmosphere/climate interaction and feedbacks, are also presented. The relative importance of several possible global climatic forcing factors including ENSO, the Indian Monsoon and solar variability modulating Antarctic sea-ice on the interannual timescale, and the modifying influence of Southern Ocean dynamics, is briefly discussed.

ANNUAL MEAN SURFACE FLUXES IN POLAR REGIONS SIMULATED WITH REMO

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For realistic simulations with a coupled atmosphere - sea ice model both model components have to yield quantitatively convincing results in uncoupled mode. Especially surface fluxes should be represented accurately because of its direct interaction with sea ice.

In preparation for a coupling of the atmospheric model REMO with a viscous-plastic sea ice model, the atmospheric model has been integrated uncoupled mode for one year over the high northern latitudes in order to validate the model results. Forcing data for REMO were taken from the ECHAM 4 AMIP run.

Although basic structures e.g. in annual mean 2m temperatures are represented fairly well, a quantitative comparison with NCEP/NCAR reanalysis data shows significantly higher temperatures in certain arctic regions. The reason for these discrepancies are relatively high polar air temperatures in the forcing data. Momentum flux, which is the dominant force for sea ice drift, shows qualitatively good results compared with observations. The winterly iceland depression is simulated fairly well which results in an acceptable flow regime.

It follows that the performance of the regional atmospheric model is to a large degree dependent on the quality of the forcing data.

VARIABILITY OF A 40–YEAR SIMULATION OF THE ARCTIC SEA ICE COVER

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The interaction between atmosphere and ocean in polar regions is investigated with a dynamic-thermodynamic sea ice model. The model is integrated over 40 years with a daily time step.

Daily fields of wind and temperature for the period 1957–1996 derived from the NCEP/NCAR reanalysis project are used as atmospheric surface forcing. The simulation results (sea ice thickness, extent, drift, volume export through Fram Strait) show high variability at all timescales. Annual means of the ice volume export through Fram Strait for different years differ by up to a factor of 2. Simulated values of ice export agree well with those derived from observations. The highest annual mean exports are found in 1968 and 1995. The time series of the sea ice extent and the melt rate within the Greenland/Iceland/Norwegian-Sea peak significantly in 1968, when the Great Salinity Anomaly was observed north of Iceland. Also, statistically significant correlations between the winter ice export and atmospheric circulation patterns, e.g. the North Atlantic Oscillation index, are found.

USING OBSERVED AND SIMULATED ^{129}I AND ^{137}Cs DISTRIBUTIONS FOR TRACING ARCTIC OCEAN CIRCULATION

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The radionuclides ^{129}I and ^{137}Cs have been released from the European reprocessing plants in Sellafield (UK) and La Hague (France) since the 1960s. In recent years, they have been used as tracers for the circulation of Atlantic Water in the Arctic Ocean. Due to different release functions and almost conservative behaviour in the water column, the ^{129}I/^{137}Cs tracer pair can be used to deduce tracer transit times from a reference point in the Norwegian Coastal Cureent since 1987.

A proxy time series for ^{129}I and ^{137}Cs concentrations at the reference point is used as a tracer source in an Arctic Ocean circulation model. The results for the period 1965-1995 are compared with available observations. The simulated large scale patterns of ^{129}I and ^{137}Cs concentrations in surface, halocline and Atlantic Waters are in good agreement with measurements from the central Arctic. Simulated tracer transit times compare well with the values derived from the measured ^{129}I and ^{137}Cs values.

However, the model results disagree with high values of ^{129}I in the Kara Sea, measured in the mid 1990s. In order to investigate this disagreement, an additional high resolution Kara Sea model is used to simulate the fine scale structure for ^{129}I and ^{137}Cs distributions as a result of inflowing Atlantic Waters and potential river sources.

THERMOHALINE STRUCTURE AND MACROSCALE VARIABILITY OF THE ARCTIC OCEAN

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Using data from about 350,000 hydrographic stations throughout the Arctic Basin, a US-Russian team constructed gridded fields of temperature and salinity for four decadal periods (1951-60; 1961-70, 1971-80, and 1981-90), see Joint US-Russian Atlas of the Arctic Ocean prepared by the Environmental Working Group of the Gore-Chernomyrdin Commission (winter period published in 1997; summer period in 1998). The analyzed fields are used to estimate the decadal scale variability and trends of the principal hydrographic variables (temperature, salinity, heat storage, and water mass characterization) for the surface, intermediate, and deep waters. Additionally, the interannual variability of the surface and halocline waters are studied using dynamic heights, depths of the upper boundary of the Atlantic waters, river run-off, sea level oscillations and ice conditions in the marginal Siberian seas.

A MIXED-LAYER MODEL OF THE SOUTHERN OCEAN FORCED BY SATELLITE-DERIVED ICE CONCENTRATIONS

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The oceanic mixed-layer of the Southern Ocean plays an important role as the interface between the warm and salty deep water and the sea ice. Whereas over the continental shelf the water is generally well mixed, ice formation and resultant dense water formation is largely dependent on the entrainment of deep water into the mixed-layer. Antarctic-wide estimates are difficult to obtain because in-situ measurements are sparse and computer models can not resolve all of the important smaller scale features such as coastal polynyas and small lead openings in the winter ice. The problem is that the large-scale wind fields used by computer models can not resolve small-scale divergences that result in areas of less ice coverage. Also small errors in near-surface air temperature can lead to significantly different ice extents. For these reasons, in this study of Southern Ocean mixed-layer properties, satellite passive microwave data from the Special Sensor Microwave/Imager (SSM/I) are used to characterize at a relatively high resolution (compared to models) the Southern Ocean sea ice cover. Temperature and wind fields from the European Centre of Mediumrange Weather Forecast (ECMWF) are used only to provide wind speed and temperature in the calculation of salt and heat fluxes. The combined data are used to run a bulk mixed layer model for the entire Southern Ocean. Deep ocean temperature and salinity is obtained from the NOAA World Ocean Atlas. The results show significant regional and seasonal differences in the mixed layer properties (temperature, salinity, depth) consistent with the limited oceanographic measurements that are available.

COUPLING PROCESSES IN HIGH LATITUDES IN THE IPSL GLOBAL COUPLED MODEL

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We analyze coupling processes in high latitudes from two simulations with the low resolution version of the IPSL (Paris, France) global ocean-atmosphere coupled model. No flux correction technique is used at the air-sea interface. The two simulations differ only by the representation of sea ice. The first one which is stable on 100 years uses a crude parametrization of sea ice. The second one includes the thermodynamic sea ice model developed at LODyC.
The study focuses mainly on the Arctic basin, and discuss the impacts of different coupling processes on the dynamic of this basin :
- sea ice behavior
- fresh water budget, and especially impact of major Siberian river runoff
- heat fluxes and joined feedbacks
- atmospheric circulation and surface currents
- link with the mid-latitudes
In particular, we show in the first simulation an isolation of the Arctic basin and consequently a decrease of deep water formation in the North Atlantic. We also stress on the changes in seasonal cycle induced by the introduction of the more physical sea ice representation.

VALIDATION OF A LARGE-SCALE SEA-ICE MODEL WITH SSM/I DERIVED SEA-ICE DRIFT FIELDS FOR THE ARCTIC

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Numerical models are used to simulate the long-term variability of the sea ice in the Arctic. To validate these models data fields with high spatial and temporal resolution are required.
First, a method of determining the large-scale sea ice drift using 85.5GHz SSM/I data is presented. A cross-correlation method is applied to sequential images of gridded data covering the entire Arctic. The algorithm estimates the mean drift velocity with an accuracy better than $1cms^{-1}$. Comparisons of individual correlation results with ice velocities measured from buoy data shows the reliability of this method. The mean values and the variabilities of the ice drift derived from satellite data correspond closely with the buoy data.
In a second step an optimized large-scale thermodynamic-dynamic sea-ice model is validated with the satellite data for the Arctic region. The atmospheric forcing of the sea-ice model is prescribed with data of the NCEP reanalysis program for the period from 1979 to 1995. Satellite retrieved ice drift and results from the numerical model are in a good agreement for periods from several days up to seasonal means. On this basis the sea-ice budget of different regions, especially of the Fram Strait, is calculated.

The description of atmospheric surface layer-sea ice- sea surface layer interaction processes in climatic models.

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The results of numerical experiments with zero-dimensional thermodynamic and two-dimensional dynamic-thermodynamic models of sea ice cover on the accuracy of reproducing turbulent and radiation heat fluxes on both boundaries of snow-ice cover in comparison with experimental data are shown.It is demonstrated that simple description of spectral absorption of solar radiation in leads together with Monin-Obukhov parameterization of turbulent heat fluxes and Konig-Langlo,Augstein parameterization of longwave radiation balance allow to receive a good agreement with observations of leads spatial distribution as well as temporal variability of mean water temperature in leads and heat flux from upper sea layer to the bottom of sea ice.Also the role of snow precipitation in sea ice growth and melting is investigated.

TIME SERIES OF PCO2, SST AND FLUORESCENCE DATA MEASURED BY CARIOCA BUOYS DRIFTING IN THE GREENLAND SEA BETWEEN AUGUST 1996 AND APRIL 1997.

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As part of the EEC - MAST program ESOP2, a Carioca buoy was deployed from the James Clark Ross at 75N - 3W on august 2, 1996. It drifted first in the Greenland Sea and then the Lofoten basin. Hourly measurements of PCO_2, SST and fluorescence were made during its 6 months lifetime. Two other buoys were deployed in the Greenland Gyre in november 1996 and march 1997, with lifetimes of 9 and 35 days, respectively.
The overall picture of PCO_2 variations in the Greenland Sea Gyre over the period august 1996 - april 1997 is the following : 1) PCO_2 values as low as 260 µatm are observed in early august, as a result of late spring or early summer biological pumping, 2) in the second half of august, a rapid increase of PCO_2 up to 320 µatm is observed, concommitant with the cooling of the surface layer from 6°C to 4°C. Mixing with deeper layers enriched in CO_2 is the cause of these observations, 3) the following measurements made between september 1996 and early april 1997, are distributed around a mean value of 310 µatm with a range of variation equal to +/- 10 µatm. These results show that the Greenland Sea Gyre is a permanent sink for atmospheric CO_2, throughout the whole year. The larger (PCO_2 air-PCO_2 sea) gradient is observed during the summer months as a result of biological pumping. Air-sea CO_2 fluxes are computed using the ECMWF wind fields prepared by the Danish Meteorological Institute.

A New Research Initiative for the Coupled Air-ice-ocean System in the Arctic

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The Arctic climate system has shown clear variabilities with various time scales, from seasonal to interdecadal. Its unique characteristics obviously plays an important role in the climate change: sea ice and snow reflect short-wave radiation providing positive albedo feedback for climate change, while the ice cover works as an insulator for the relatively warm ocean. The formation of sea ice results in the brine rejection, which yields a water mass characteristic of high latitude regions. The Arctic Ocean has an important role for the global ocean. Deep water formed in the Greenland Sea is the largest water source of the global ocean, while its formation rate has been found to be reduced in the last decade. It appears that the ice exports, from the Arctic Ocean to the convective regions, prevent deep convection. The surprising change that has recently been found is the further intrusion of the Atlantic Water into the intermediate depth of the Arctic. This intrusion may yield significant reduction of the ice cover and make the upper Arctic water lighter. Arctic haze, vapor balance and polar vortex are thought to play important roles also.

A new research initiative is just begun at the International Arctic Research Center (IARC) at the University of Alaska, Fairbanks. Frontier Research System for Earth Sciences is paritipating in the IARC as a significant component concentrating on the atmospheric-ice-ocean part of the Arctic system. Frontier plans to tackle several selected processes important for Arctic climate change, simultaneously testing their effects on the climate change using ice-ocean GCMs and coupled atmospheric-ocean GCMs. Data assimilation is another tool to be used for analyzing past climate change and veryfing GCMs.

A MODEL FOR THE TIME EVOLUTION OF A LATENT HEAT POLYNYA ON THE LEE SIDE OF AN ISLAND. APPLICATION TO THE ST. LAWRENCE ISLAND POLYNYA

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The one-dimensional time-dependent model of a wind-driven coastal polynya developed by Pease (1987) and Ou(1988) is extended to two dimensions. The model solves for the evolution of the polynya edge as a function of the transports of consolidated and frazil ice and the frazil ice production rate. All three variables are determined from prescribed wind velocity and radiative and turbulent heat fluxes at the surface. The model takes also into account the shape of the coastline, which dictates the actual geometry of the polynya edge. Analytical solutions of the model are found for a simple island coastline consisting of a straight segment of finite length. Two parameters are shown to be of fundamental importance to characterise the shape and size of the polynya: the asymptotic polynya width, L_w, and the longshore adjustment lenghtscale, L_a. The length L_w determines the offshore equilibrium width of the polynya for a coastline of infinite length. The length L_a measures the sensitivity of the polynya edge to longshore variations in the coastline shape and, in particular, to its total extent. It is shown that if L_a is comparable to L_w the size of the polynya can be very different from that obtained by one-dimensional models. The model is applied to the study of mesoscale variability in the St. Lawrence Island Polynya.

SUBMARINE-BASED CURRENT MEASUREMENTS IN THE ARCTIC OCEAN: SOME EARLY RESULTS

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Research cruises were carried out in the central Arctic Ocean aboard USN submarines in autumn 1996 and 1997 under the auspices of the SCientific ICe EXpedition (SCICEX) program. An upward-looking 150-kHz acoustic doppler current profiler (adcp) was hull-mounted for each cruise and continuously measured vertical current profiles from the cruising depth, typically 100-200 m, upward to the sea ice cover. Ancillary water property data were collected by a continuously recording conductivity/temperature/depth (CTD) system mounted atop the sail and by expendable CTD (XCTD) traces obtained at regular intervals from the surface down to about 1000 m depth. The current data provided vertical current shear across the cold halocline and will be used in conjunction with the CTD data to estimate vertical turbulent heat fluxes for different parts of the Arctic Ocean. The data also allowed detection of mesoscale eddies along the cruise track, providing an estimate of the eddy density. Two eddies were surveyed, one during each of the two field seasons. These features had ring-like characteristics with maximum tangential speeds exceeding 20 cm/s and warm cores. Ongoing analyses of the entrapped water characteristics and internal structure will yield information on sources and local influences on ocean mixing. These studies are intended to yield information on the heat budget and ventilation of the interior Arctic Ocean.

LAPTEV'S SEA LEVEL VARIABILITY IN CONNECTION WITH GREEN HOUSE EFFECTS

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Taking into account the main features of previous palae coastal evolution, the expecting sea level uplifting connected with the green house effects could be compaired with palae changing during Sangamon time, Late Pleistocene (in Siberia - Kazantsev period). The real ground value will be connected with the total duration of warming so as local geological and geomorphological features including permofrost spreading and neotectonical activity. Within some regions such as Anabar - Olenek area will widely increased thermoabrational processes (nowdays the degradation of the shoreline is more then 8 meter per year); at another regions - with sedimentary rocks and geological outcrops, the uplifting effects will be not so large and be fixed in some erosional terraces. According to our data the most intensive effects will be within Jana basin and Khatanga bays. Climate regime will come humidity with intensive thermofrost degradation and erosional activity.

COASTAL GEODYNAMICS OF CHUKCHY SEA

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The Chukchy shoreline extention (with islands) is around 1600 km. Wave energy is the main dynamical factor and accumulative coasts occupy more then 50% of the total shoreline lenght. Bars and bay bars are the typical relief that closely connected with the local neotectonical movements of different types. Lagoon coasts occupy the neotectonical downlifting areas in contrast with abrasional capes. Within the area cape Shmidt - cape Vankarem the range of downlifting is increased from the west to the east. Geodynamical differences are fixed in the inner shelf too - at accumulative parts so as erosional ones. The accumulative parts have had 0,001-0,0009 (in tg) surface gradients with predominance of good sorting sands (So= 1.1-1.7) and the erosional are more deep (gradient 0,004-0,07), sediments more coarse (up to the gravel) and bad sorting (So= 4.1-12.2). Palae shorelines are concentrated on the next seabed levels: 4-5 m; 8-12 m; 15-16 m (marine terraces, bars); 21-25 m (beaches, erosional palaerelief); 28-30 m; 31-36 m and 40-45 m (large complex of relict forms). Shorelines at 31-36 m are dated about 11 000 - 12 000 years and at 40-45m - 15 000 years. Our data have got a good correlation with the next regions (Sea of Okhotsk, Laptev Sea etc.) and reflect the global processes of the last sea level rising.

ARCTIC SEA ICE VARIABILITY

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Analysis of 18.2 years of passive microwave satellite data, from October 1978 through December 1996, reveals an overall decrease in Arctic sea ice extents, although with strong regional, seasonal, and interannual variabilities. Regionally, the most striking decreases occur in the Sea of Okhotsk and the Kara and Barents Seas, with smaller decreases of statistical significance in the Arctic Ocean, the Greenland Sea, and Hudson Bay. The only region showing a statistically significant increase is the Gulf of St. Lawrence. Seasonally, while there is a decrease in total ice extent during all seasons, the greatest decrease is in spring, the second greatest in summer. All regions show interannual variabilities, with those in the Greenland Sea and the Kara and Barents Seas, two regions under the influence of North Atlantic storm systems, being particularly high. Overall, the decrease in Arctic ice extents averages 2.7+0.4% per decade, with a predominant periodicity of about 5 years.

SENSITIVITY STUDIES FOR MODELING THE GIN AND BARENTS SEAS WITH NORTH ATLANTIC AND ARCTIC MODELS

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The GIN and Barents Seas regions have been modelled usually as part of North Atlantic, global or Arctic simulation efforts. The North Atlantic and global studies, using mainly spherical grids, suffer from a latitude limit or polar inaccuracies. The Arctic studies, using either rotated spherical or polar stereographic grids, suffer from inadequate boundary conditions in the Atlantic boundary portions. This study has compared spherical North Atlantic and polar stereographic Arctic simulations that had approximately the same resolution in the Fram Strait or in the Iceland-Faroe Channel. In general, the Arctic simulations do not represent well the various branchings of the North Atlantic Inflow Current, and the Atlantic simulations yield weaker East Greenland and Jan Mayen Currents. A coupled model improves on both current systems, despite coupling errors.

PRELIMINARY STUDY ON VARIABILITY OF ARCTIC SEA ICE EXTENT

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Based on a dataset of observed sea ice concentrations on a standard 1-degree grid (cylindrical projection) in the Arctic region during 1901-1995, seasonal and nonseasonal variability of sea ice area is studied. Considering the differences of topography among sectors over the Arctic region, the whole Arctic region is divided into eight independent sectors by their geographical characteristics. Sea ice areas in different sectors display the same annual cycle, but the spatial differences are significant in nonseasonal variability. Principal Component Analysis (PCA) is applied to describe the spatial characteristics of nonseasonal variability of sea ice area. The first EOF of Arctic sea ice areas in eight sectors shows coherent variation in all sectors, centred in sectors of the Laptev Sea and the East Siberian Sea, the corresponding PC explaining 40.0 % of total variance. The second EOF reflects the different variations between the sectors of the Greenland Sea, the Barents Sea, the Kara Sea and all other sectors. Correlations between Arctic sea ice area and Southern Oscillation are analysed by time-lag correlation coeffients between sea ice area and SOI. Significant correlations have been found.

LARGE SCALE MODELLING OF THE GREENLAND ICELAND AND NORWEGIAN SEAS

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This study explores the circulation of water masses and ice in the Greenland, Iceland and Norwegian Seas. It represents one of the modelling components of the European Sub-Polar Ocean Programme, (ESOP-2), in which the role played by sea ice in the energetics of the GIN Seas is explored. Towards this goal a coupled ice-ocean model has been set-up. The objective of this study is to carry out a four year simulation using atmospheric forcing from a meteorological model. A number of shorter period simulations will be described in this talk. These include a preliminary tracer study in order to simulate the results of the SF6 tracer released into the Greenland Sea in August 1996. While the initial numerical experiments are encouraging a number of model areas have been identified that require further improvement, notably the coarse vertical resolution employed. The surface mixed layer response is crucial to the success of the four year coupled ice ocean simulation and two alternative vertical grids have been tried. The grids take advantage of a new hydrostatic, general vertical co-ordinate, version of MIKE 3. This version allows the grid to be refined near the surface. Alternative methods for handling the open boundaries are also described, including collaborative efforts with ESOP partners. The ice modelling component has been further developed and results from the coupled sea-ice experiments are discussed.

A HIGH RESOLUTION SIMULATION OF THE GREENLAND SEA GYRO WITH A COUPLED AIR-SEA-ICE REGIONAL MODEL

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The strong air-sea-ice interaction in the Greenland Gyro region is believed to play an important role in the Earth's climate system through their controlling role in the thermohaline circulation. To model the physical processes in a consistent way, coupled air-sea-ice models are required. Furthermore, the complicated bathymetry of the region suggests that high spatial resolution also seems important in order to handle the processes realistically.
With emphasis on the interaction between the atmosphere and the ice-ocean systems the significance of the feed-back mechanisms has been studied. The role of such feed-back mechanisms has been addressed using a fully coupled three dimensional atmosphere-ice-ocean model. The atmospheric model component is the HIRHAM model (with the adiabatic part based on the short term forecast modeling system; HIRLAM, and physical parameterizations from the ECHAM4 climate model of the Max Planck Institute for Meteorology). The ocean-seaice component is the MIKE 3 model developed at the Danish Hydraulic Institute. Results from month long simulations will be presented. Periods with intensive field activities in the area related to the ESOP-2 (European Subpolar Ocean Programme, Phase 2) project have been chosen. The main focus will be on the air-sea interactions, but also the general oceanic flow will be addressed.

ICEBERGS AS TRIGGERS FOR ABRUPT CLIMATE CHANGES

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Typical perturbations induced by icebergs au traverse during austral winter 1997 along Antarctic coastline showed decrease of atmospheric pressure(up to 0.4 hPa), humidity(2-4%),air temperature(1 C),wind speed(4-6 m/s) and increase of wind direction(up to 20 degrees) and water temperature(up to 1-2 C), accompanying the leads provided by moving icebergs in the ice cover with the lateral dimensions exceeding 8-10 times the dimensions of icebergs themselves. Since an iceberg is a part of Antarctic glacier ice cover it's not surprising to find the water and atmosphere circulation patterns coinciding with the proper scaling.Keeping in mind the latest results in climate studies it's tempting to consider icebergs induced perturbations in ocean and atmosphere as triggering mechanism for abrupt climate changes.

THE IMPORTANCE OF ADVECTION, FRONTAL MIXING AND SLOPE CONVECTION FOR THE ARCTIC OCEAN INTERMEDIATE AND DEEP WATER CHARACTERISTICS.

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The two inflows from the Norwegian Sea to the Arctic Ocean, through Fram Strait and over the Barents Sea, converge along the continental slope east of the St. Anna Trough. The frontal zone exhibits intense interleaving and several warm cores indicating branching of the current. CTD observations made from RV Polarstern in 1995 indicated that the Fram Strait inflow was largely confined to the Nansen Basin and that the Barents Sea Branch supplied most of the water to the Amundsen - and to the Canadian Basin. The boundary current is modified by slope convection and the observations are used to examine the effects of different entrainment rates on the water mass properties of the boundary current. The characteristics of the deep basins are conditioned by injections from the boundary current. Assuming that 0.5Sv crosses the Lomonosov Ridge at the Siberian continental slope, about 100 years are needed to remove the mis-match between water properties of the boundary current and those of the deep Canadian Basin between 200 and 1700m, caused by the recent higher Atlantic Layer temperatures in the boundary current. The Eurasian Basin Deep Water properties suggest more complicated interactions involving the St Anna inflow as well as dense, brine-enriched shelf water.

Hydrographic conditions in northern Fram Strait.

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The West Spitsbergen Current splits as it reaches the northern Fram Strait. One branch follows the Svalbard continental slope eastward while a second branch stays west of the Yermak Plateau. Observations made from R/V Polarstern in summer 1997 showed that the main inflow of Atlantic Water to the Arctic Ocean occurred close to Svalbard, while the stream north of the Yermak Plateau was weak and narrow. In addition to Atlantic Water this branch also transports Norwegian Sea Deep Water into the Eurasian Basin. The water column above the south-eastern flank of the Yermak Plateau was distinctly colder and fresher than the two inflow branches. No indication of recirculating water was seen on the section between the Yermak Plateau and the Greenland continental shelf. The waters mainly derived from the Eurasian Basin, displaying the higher temperature of the Atlantic Layer and the cold, deep and saline Mixed Layer recently reported from that basin. Close to the Greenland continental slope a Canadian Basin water column be could be recognised. The Mixed Layer salinity was low and at one station the temperature of the Atlantic Layer was below 0.5°C. This suggests that the high temperature pulse in the Atlantic Layer has not yet made a complete circuit around the Arctic Ocean.

Characteristics of the Denmark Strait overflow plume in fall 1997.

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The Denmark Strait is perhaps the most important exit for the water masses formed in the Arctic Mediterranean Sea. The East Greenland Current carries the less dense Polar Surface Water, different intermediate waters masses as well as deep waters originating in the Arctic Ocean. The Denmark Strait overflow thus supplies a substantial fraction of the North Atlantic Deep Water. In August-September 1997 R/V Aranda of the Finnish Institute of Marine Research conducted a CTD and ADCP survey in the Denmark Strait within the framework of the EC funded programme VEINS. The observations indicate that the densest layers recirculate eastward along the Iceland continental slope and only occasionally cross the sill. The main supply to the Denmark Strait Overflow Water is drawn from the intermediate waters forming the upstream temperature maximum of the East Greenland Current. The sill the descending plume is stratified and its densest part is frequently capped by a less saline and occasionally colder layer with TS characteristics close to those of the thermocline above the upstream temperature maximum suggesting polar origin. Due to its comparatively low density this layer must not pass trough the deepest part of the strait but may flow over the shelf further to the west and drain down the continental slope south of the sill. The presence of a low salinity lid in the Denmark Strait overflow plume would imply that the entrainment of ambient water is small as the plume sinks down to 2000m.

THE REGIONAL IMPACT OF A LEAD MODEL ON SEA ICE CONCENTRATION

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ICESTATE dynamic and thermodynamic sea ice model was initiated in the framework of the "Ice State" European project at NERSC, Norway (1996), and was further developped at CNRM, and then coupled to OPA OGCM (LODYC, Paris). As a coupled model, ICESTATE needed to return realistic ocean-atmosphere heat and fresh water fluxes.
There the role of leads is definitely crucial. In the wintertime, heat fluxes over leads can be nearly two orders of magnitude larger than those on ice or snow. Thus bad estimates of lead extent (mainly triggered by sea ice dynamics) cause serious mistakes as far as these fluxes are concerned. In summer, not only the dynamics plays a major role in shaping open water fraction, but also sea ice lateral melting. This phenomenon takes place because at this time of the year leads absorb solar short wave energy; sea ice in contact with warm water melts laterally, the melting rate being a function of lead temperature and width. Results of such a parameterization will be presented, and compared with the effects of dynamics on sea ice lead opening and closing.

THE GENERAL CIRCULATION, THERMODYNAMICS AND WATER MASS TRANSFORMATION IN THE GREENLAND SEA

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In this study an Atlantic Ocean, Nordic Seas, and Arctic Ocean version of the 3-dimensional Miami Isopycnic Coordinate Ocean Model MICOM is formulated in order to simulate the general circulation, the thermodynamics, and the water mass transformation in the Greenland Sea and the adjoining regions. Simulations with climatological (monthly mean) and synoptic (6 hr and daily) forcing fields are presented. Parts of the analysis include a multi-tracer simulation in which the major water masses of Arctic and Atlantic origin are tagged and followed on decadal timescales. In this way, the relative importance of mixed layer entrainment/detrainment, convectice mixing, and diapycnal mixing on the water mass transformation is quantified. The study is a part of the ESOP2 project under the EU-MAST III Programme.

INTERANNUAL VARIABILITY OF A DENSE BOTTOM WATER PLUME IN THE WESTERN BARENTS SEA

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Cold, brine-enriched waters generated through ice formation in near-shore areas of the shelf seas contribute to the ventilation of the deep Arctic Ocean. The generation and downstream change of a shelf water plume was studied with moored instruments south of Svalbard which were deployed from August 1993 to September 1994. Cold bottom water with temperatures close to the freezing point drained from Storfjord continuously from March until September with a mean speed of 0.14 m/s. About 43 days after the plume front had left southern edge of the Storfjord, it reached the shelf break at a distance of 150 km. The plume spread in the horizontal to twice its initial width, but its thickness of about 40 m remained almost constant. The temperatures and salinities in the plume increased. The volume transport and the change of temperature/salinity properties indicate entrainment of an equal amount of Atlantic water into the plume between the production area and the shelf edge. Compared to earlyer observations (1991/92), the bottom water salinity was low in 1993/94, while the TS-ranges of the Atlantic water remained almost constant. Since the density difference drives the plume flow, the speed of the plume was lower in 1993/94. The lower salinity of the plume in 1993/94 is the consequence of a weaker ice formation in Storfjord and of lower surface salinities in the northern Barents Sea. During 1993/94 the plume was too light to sink below 500 m. Our observations showed the effect of interannual variations of the regional atmospheric forcing on the ventilation depth of the Nordic Seas and subsequently of the Arctic Ocean.

MODIFICATION OF WATERS IN THE BARENTS SEA AND THEIR INPUT TO THE EURASIAN BASIN THROUGH ST. ANNA TROUGH

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The ventilation of the interior Arctic Ocean depends significantly upon the input of water from the Barents and Kara Seas descending down the St. Anna Trough. This water is formed through modification of the warm, saline inflow of Atlantic origin from the Norwegian Sea and low salinity water supplied by the Norwegian Coastal Current in the south, and through melting of ice advected from the central Arctic Ocean and the Kara Sea. Lateral mixing, cooling and the freezing/melting cycle with release of brine form three distinct modes, which leave the Barents Sea eastward, either seasonally or throughout the year. The largest contribution is the most saline but only moderately cold bottom water produced west of Novaya Zemlya. At present, all three modes constitute a low salinity input to the Arctic Ocean. Using hydrographic observations from 1991 and 1996 in the Barents Sea and along the shelf edge of the Kara Sea and time series of current, temperature and salinity from moorings in the eastern Barents Sea, we trace the flow and the modification of the water masses from the western Barents Sea through the passage between Novaya Zemlya and Franz-Josef-Land to the St. Anna Trough.

OA6

RETREAT OF THE COLD HALOCLINE LAYER IN THE ARCTIC OCEAN

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We present a comparison of Arctic Ocean hydrographic data sets from the 1990's, with a focus on changes in the upper few hundred meters of the Eurasian Basin. These comparisons reveal that the Eurasian Basin "cold halocline layer" has retreated during the 1990's to cover significantly less area than in previous years. Specifically, we find a retreat from the Amundsen Basin back into the Makarov Basin; the latter is the only region with a true cold halocline layer during 1995. Changes are also seen in other halocline types and in the Atlantic Water layer heat content and depth. Using a simple mixing model, we calculate maximum ice-ocean heat fluxes of 1-3 W/m2 during winter in the Eurasian Basin. We speculate that changes in sea ice motion and winds during the 1990's have influenced the location where fresh shelf waters flow into the deeper basins of the Arctic Ocean.

NATURAL CYCLES AND PATTERNS AMONG THE UPPER OCEAN CIRCULATION OF THE ARCTIC OCEAN, SURFACE WIND, AND SEA ICE EXTENT IN THE SIBERIAN SEAS

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The transpolar drift stream is a semi-permanent circulation feature by which ice formed in the Siberian marginal seas is transported across the Arctic Basin, through the Fram Strait, and into the Nordic Seas. This feature of sea ice motion is due equally to surface winds and to surface ocean currents. For this study, the upper ocean circulation is represented by annual late winter fields of dynamic height (surface to 200 db); surface winds are directly related to surface pressure fields; and ice conditions are characterized by the fractional area of late summer ice in different regions along the Siberian shelf. Long term records (1954-1990) of upper ocean circulation, surface wind, and ice conditions are analyzed, and a time lagged covariance study suggests coupled patterns and natural oscillations among the three variables. For example, anomalous upper ocean circulation patterns are related to future anomalous ice conditions in the Laptev and East Siberian Seas. Physical mechanisms may be associated with the role of shelf currents in exchanging ice and/or heat between the Siberian shelves and the deep basin. The time lagged study also shows covariance between anomalous ice conditions and future upper ocean circulation anomalies. This pair of lagged covariances may be interpreted as a self oscillating system with a period of about 6 years.

COMPARISON OF SIMULATED AND OBSERVED SEA ICE ROUGHNESS

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A quantitative relationship between observed sea ice roughness and simulated large-scale deformation work is established in order to provide new means for model validation and a better representation of the sea ice component in climate modelling. Sea ice Roughness R is introduced as an additional prognostic variable in a dynamic-thermodynamic sea ice model with a viscous-plastic rheology. It is defined as the accumulated work of internal forces acting upon an ice volume, given in energy per unit area. A fraction of this total deformation work is equated to the potential energy stored in pressure ridges. Using ridge geometries and distribution functions from observations, observable quantities like mean keel draft, number of keels per distance as well as volumetric and areal fractions of deformed ice are derived from the simulated ice roughness. Comparisons of these simulated quantities with measurements (submarineborne sonars, laser altimeters on helicopters) show good agreement both in the Arctic and Weddell Sea. Satelliteborne observations of sea ice roughness now under development will provide an even larger data set which will be used for model verification. Influences of the simulated sea ice roughness on heat and momentum exchanges between ocean and atmosphere are also shown. The simulations indicate that the inclusion of sea ice roughness provides for a more realistic representation of the boundary layer processes in AOGCMs.

DYNAMICS AND THERMODYNAMICS OF SEA ICE LEADS IN THE WEDDELL SEA

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During winter conditions, the opening and closing of leads and polynyas in sea ice covered regions play a major role in the heat exchange between the ocean and the atmosphere, because the freezing rate at the water surface is by up to two orders of magnitude greater than at the bottom of a closed ice pack. In this contribution, the frequence of lead and polynya occurence in the Weddell Sea in July 1992 is investigated using an ERS-1 SAR data set, and the connection of opening and closing processes to the synoptic situation described by EZMW analysis are investigated. In the central Weddell Sea, the ice motion can mostly be considered as free drift and is, as well as divergence and convergence in the ice velocity field, mainly wind driven. In most cases, the shape and orientation of leads is correlated to their position relative to moving cyclones. Using climatological and EZMW data about frequency and tracks of the cyclones in the region considered, an estimate of turbulent heat fluxes form the ocean to the atmosphere and of the monthly ice production rate is given. The results can be used for assessment of coupled sea ice–ocean models as well as a basic method to forecast the developement of leads using the sea level wind field forecast.

The climate sensitivity of the Arctic ocean ice cover; Some results from a fully coupled atmosphere-ice-ocean column model.

Johan Svderkvist, Gvran Bjvrk

A fully coupled column model for the upper ocean, ice cover and the atmosphere in the Arctic is presented. The ocean model is an one-dimensional column with a mixed layer on top (Bjvrk 1989) and the ice model includes a thickness distribution of both unridged and ridged ice (Bjvrk 1992). The atmosphere model is an analytical one-dimensional column model (Thorndike 1992). The improvement with the present model is that a single atmospheric column is coupled to a mosaic of different surface conditions, such that it integrates the effect of different heat fluxes due to the ice thickness distribution. Linearization of the heat fluxes, together with the assumption that the sea/ice surface is in thermal equilibrium with the atmosphere, makes the coupling between the atmospheric and the ice-ocean model to a linear problem. The coupled model computes the longwave incoming radiation, air temperature and mean surface temperature, given the ice thickness distribution and the advected atmospheric heat from lower latitudes. The sensitivity of the model ice cover to different climatic quantities as the advected atmospheric heat, optical depth, ice export and ice ridging, are presented.

PRECONDITIONS FOR CONVECTION IN THE GREENLAND SEA.

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A combination of SSM/I passive microwave observations of ice concentrations, buoy drift data and ECMWF wind data are used to drive a model of ice growth, melt and advection for a small area around 75N,0W in the center fo the Greenland Sea. The model calculates the resulting salt flux to the ocean on a daily basis throughout the winter of 1996-1997, and results are compared with salinity and density profiles from a number of cruises to the area during the first field season of ESOP-2 (the European Subpolar Ocean Programme), and they indicate that the salt released from ice growth are an important prerequisite for subsequent convection. Results are also related to ERS-2 SAR images of the area during the winter.

MECHANISMS OF DEEP WATER FORMATION AND MODIFICATION IN THE GREENLAND SEA

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In the central Greenland Sea, deep convection below 2000m ceased almost completely since the early 1980s. In the 1990s, convection took place up to maximum depths of 1500m. However, the characteristics of the deep water changed slowly over the past couple of years. Since this occured in the absence of deep convection, other processes must play a key role in this modification. Recently, a new mechanism concerning the formation and alteration of Greenland Sea deep water by enhanced boundary layer mixing has been proposed. The diapycnal exchange between the ventilated intermediate water masses and the deep water might explain the observed augmentation in tracer concentration which could not be established by lateral exchange.

A box model including heat and anthropogenic tracers (CFC's) is used to quantify the renewal times of the deep water and to estimate the diapycnal mixing rates required by this scenario. The modeled deep water properties are then related to the existing measurements and the mixing rates are compared to those expected in a bottom boundary layer, especially above a rough topography.

ICE-OCEAN PHYSICS FROM THE MARCH 1997 *'JAN MAYEN'* CRUISE TO THE ODDEN

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During the March 1997 cruise of Jan Mayen to the Odden ice tongue, the ice cover was examined by video and photography; by direct sampling, recovery and fabric analysis of frazil and pancake ice; and by the deployment of three GPS/Argos 'pancake' buoys to track ice motion. Water structure was sampled by CTD's to 2000m, and near surface melt-freeze cycles by hand-held CTD's through ice to 100m. We present a summary of these experiments and initial results.

THE INFLUENCE OF OCEANIC CONVECTION IN CARBON DISTRIBUTION

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The influence of open ocean convection in the CO_2 - Concentration of the ocean was investigated by a numerical model study. A carbon cycle model is coupled to a 2.5 - dimensional non - hydrostatic convection model to study the efficiency of deep winter convection, the gas exchange between ocean surface and atmosphere and the mixing processes within the ocean. The convection model is interactively coupled to a simple thermo-hydrodynamic sea ice model. The model domain is a vertical ocean slice with an isotropic grid size of 10 meters and with cyclic boundary conditions. Equal eddy viscosity and diffusivity coefficients are applied for horizontal as well as for the vertical dimensions. The gas exchange with the atmosphere is modeled using a volatilation rate which considers the relationship between wind speed and partial pressure difference. For the simulation we used an observed stratification from the centre of the Greenland Sea and realistic atmospheric forcing (ECMWF) for transient momentum and heat fluxes. In this simulation the concentration are not influenced by horizontal advection, which is small in the centre of the Greenland Sea Gyre.

DECADAL VARIABILITY IN A COUPLED SEA ICE-OCEAN-ATMOSPHERE MODEL

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An inhomogeneous reduced gravity upper ocean model is coupled to a dynamic/thermodynamic sea ice model and a 2-dimensional atmospheric energy balance model. The coupled model is solved in a meridional channel, taken to represent the Greenland-Island-Norwegian (GIN) Sea. At the top of the atmosphere, the seasonal cycle of insolation is prescribed. The model is also driven by a climatological wind stress field, representative of that in the GIN Sea. At oceanic inflow points on the open zonal boundaries, climatological temperature and salinity values are specified, again representative of the GIN Sea. It is demonstrated that the seasonal cycle that the model spins up to is extremely sensitive to perturbations in the meridional volume transport across the northern zonal boundary. Fluctuations of the order of 0.1 Sv in this transport lead to decadal oscillations in the interior fields. For example, winter sea ice area fluctuates between 1.1×10^6 and 1.6×10^6 km^2 on a time scale of $\sim$40 years. The oscillations are associated with the passage of long baroclinic Rossby waves generated by a mass imbalance between meridional transport across the open zonal boundaries and entrainment into the upper ocean. The implications of these results for decadal variability in the GIN Sea are discussed.

INVESTIGATION OF SMALL SCALE ICE DYNAMICS WITHIN THE ODDEN BY THE USE OF A GPS/ARGOS DRIFTER

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Three revolutionarily designed GPS/Argos buoys were developed for release in the Odden region of the Greenland Sea. These buoys transmitted their GPS location (including all the GPS information needed for post differential correction), the sea surface and air temperature via the Argos satellite system. Using a novel technique of stacking the data and combining the Argos location with the GPS location (i.e. cutting down length of the GPS message) it was possible to obtain and transmit a reading every 20 minutes for the lifetime of the buoy (i.e. no holes in the data set). We show how this method delivers cleaner more reliable data than the location system used by Argos. In addition our results indicate that ice within the Odden is extremely dynamic and that its movements are influenced by passing weather systems. Also by comparing the air temperature measurements from the buoys with SSM/I ice concentration images it appears that the growth/decay of the Odden is strongly influenced by cold/warm air outbreaks.

SOUTHERN OCEAN COUPLED OCEAN/SEA-ICE MODELLING AT MEDIUM AND HIGH RESOLUTIONS

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In this study we have coupled a primitive equation ocean model to a dynamic/thermodynamic sea-ice model and applied it at coarse to medium resolution to the whole Southern Ocean and at high resolution to a region of the Southern Ocean south of Australia. The coarse to medium resolution model has been integrated for a century and the seasonal sea-ice cover exhibits a typical *thermal mode* behaviour. The high-resolution model is found to be very sensitive to surface fresh water fluxes. A stable seasonal cycle is only simulated for sufficient fresh water fluxes. For fresh water fluxes below a threshold value of around 40 cm/yr the coupled system enters a *thermal mode* characterized by vertical homogeneity of the oceanic temperature and salinity fields. Such an ocean has a surface temperature that is too warm for a sea-ice cover to develop. Spatial and temporal variability of the oceanic heat flux into the upper model layer is examined for the stable simulations. High values of this oceanic heat flux (40 W/m^2) occur during the sea-ice formation period (March-June) with values going down as low as 5 W/m^2 in November. The source of this heat is primarily convective, a process induced by brine rejection during ice growth. The model's sensitivity to freshwater fluxes in creating a seasonal sea-ice cover, which we found in these process studies, is probably causing variability in the production of Deep and Bottom Water.

OA7 Antarctic ocean circulation: observations and models

Convener: Beckmann, A.
Co-Convener: Garcia, M.A.

INTERANNUAL VARIABILITY IN THE SOUTHERN OCEAN ASSOCIATED WITH THE ANTARCTIC CIRCUMPOLAR WAVE

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Anomaly patterns in the Southern Ocean in response to oscillations in the atmospheric forcing are investigated. To this end, the Hamburg LSG OGCM is forced by wind stress, heat and fresh water fluxes derived from the ECMWF Re-Analysis (ERA) data set for the period form January 1979 to February 1994. In particular, a hindcast is made of the Antarctic Circumpolar Wave. The atmospheric patterns of the ACW (e.g. sea level pressure and the associated wind stress anomalies) are compared with other descriptions of the ACW. The simulated ocean response shows anomalies in sea water temperature and salinity which correspond well with the observed ACW. They vary with a period of 3-5 years and advect with the Antarctic Circumpolar Current. High amplitudes only occur in the South East Indian and Pacific ocean. Wind stress is identified as the dominant factor for the generation of the oceanic anomalies. A physical mechanism is proposed explaining the oceanic component of the ACW in terms of anomalous Ekman pumping and convection.

A NUMERICAL MODEL OF THE WEDDELL SEA: LARGE-SCALE CIRCULATION AND WATER MASS DISTRIBUTION

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Processes that determine the large-scale circulation in the Weddell Sea are (1) the transfer of local momentum and heat and fresh water at the sea surface, significantly modified by sea ice dynamics and thermodynamics, (2) the interaction with the Antarctic Circumpolar Current and (3) the water mass transformation beneath the ice shelves. A long-term modelling project has been initiated at AWI to investigate this complex regime, and the role of each component in this system with regard to seasonal, interannual and decadal variability. As a first step, the coupled ocean/sub-ice shelf system is investigated. A terrain-following ocean circulation model (SPEM) is used and modified for the inclusion of sub-ice shelf areas. The model configuration is circumpolar, with higher resolution (20-100 km) in the Weddell Sea sector. Six major ice shelves are included: Filchner-Ronne, Larsen, Brunt, Riiser-Larsen, Amery and Ross. The model is initialized with hydrographic data from the Southern Ocean Atlas and driven by monthly mean values of surface temperature and salinity, as obtained from a stand-along sea-ice model. The effect of the sub-ice shelf forcing is quantified in twin-experiments with and without fluxes at the base of the ice shelves. Artificial passive tracers are used to determine the pathways and time scales of water mass spreading.

Observations and modelling of large-scale variations in Antarctic seaice edge

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Using a 15-year timeseries of seaice edge from SMMR/SSMI observations, we present evidence for significant correlations between seaice edge variations at both long lags and leads (up to two years). These correlations are not stationary, however, but are advected around Antarctica in the direction of and at the approximate speed of the Antarctic Circumpolar Current. The strongest correlations occur in the Bellingshausen Sea and Weddell Sea regions and show anticorrelations between the two sides of the Antarctic Peninsula; elsewhere the connections appear much weaker. The propagation speed of these anomalies is consistent with recent suggestions of an "Antarctic Circumpolar Wave". However such a wave would be expected to lead to advecting correlations all around Antarctica, whereas we find that the correlations are strong only if the center of correlation is in the Bellingshausen Sea - Weddell Sea area.

Corresponding modelling studies with the UKMO/Hadley Centre GCM (HADCM2) show correlations that are not significant up to such long lags and leads, and which lack the significant anticorrelations shown by the observations; reasons for this will be discussed.

SONAR MEASUREMENTS OF CURRENT VELOCITIES IN THE ANTARCTIC OCEAN: RESULTS OF THE PS4 WOCE TRANSECT.

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We report results of acoustic observations of velocity structure and internal ocean processes from a transect along 67 S in the Pacific sector of the Antarctic. The transect was carried out in February-March, 1992 in a frame of WOCE Hydrographic Program. Observations were made at 113 oceanographic stations located from 70 W to 164 E. Each station included a CTD cast and simultaneous measurements of calibrated acoustic returns at frequencies of 12 kHz and 24 kHz down to 1000 m depth. Velocity data were collected with a vessel mounted 75-kHz acoustic Doppler current profiler (ADCP) to a depth of about 500 m. The results show a consistency between the remote and in situ observations. The report will cover a wide range of questions concerning similarities and differences between information obtained by means of the two techniques of ocean investigation. Particular interest will be placed on combined analysis of the features which could not be traced on the basis of the CTD data only. Problems of underwater remote studies of large-scale circulations, mesoscale and fine structure features will be highlighted on the examples of Antarctic Circumpolar current and Ross sea loop.

STRUCTURE OF THE ANTARCTIC CIRCUMPOLAR CURRENT SOUTH OF NEW ZEALAND BASED ON MOORED CURRENT MEASUREMENTS

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The structure of the Antarctic Circumpolar Current is studied using the current meter data from buoys set south of New Zealand. Direct measurements on moored buoys are analysed together with two repearted hydrographic sections approximately along 170 degrees East from 55 to 71 degrees South with a time interval of two months. The measurements confirm that the current east of the Macquarie ridge splits into two jets covering the zone from 56 to 61 degrees South. The northern part of the zone is eddy productive. Strong currents associated with the fronts reach 2000 m depth without significant decrease of velocity which exceeds 80 cm/s. The southern jet is more stable and no so deep as the northern one.

GRADUAL WARMING OF THE WEDDELL DEEP AND BOTTOM WATER

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The Weddell Sea is known to be one of the areas of major water mass modifications in the ocean. It feeds Weddell Sea Deep and Bottom Water into the circumpolar water belt from where the water masses spread as Antarctic Bottom Water into the basins of all three oceans. Between October 1989 and May 1996 five cruises with "Polarstern" were carried out to measure the water mass properties in the Weddell Sea by means of CTD and tracer surveys as well as by an extensive mooring programme. The measurements show a consistent increase of the temperature of the Warm Deep Water and Weddell Sea Bottom Water layers of large parts of the Weddell Sea indicating, that the inflow from the Antarctic Circumpolar Current into the Weddell Gyre is either enhanced or has changed its characteristics since 1984. The variation of the major source water mass can be followed from the central to the western Weddell Sea. It leads either to a reduction of the bottom water formation or to a change of the characteristics of the recently formed bottom water. An alternative explanation of the bottom water warming is the reduction of Ice Shelf Water outflow from the Filchner/Ronne Ice Shelf which is observed since several years.

One-year records of currents, temperature and salinity near the Ronne Ice Shelf, the Weddell Sea

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Registrations from a current meter mooring in the period February 1993 to April 1994 near the Ronne Ice Shelf are presented. The mooring was positioned near 53(W where the relative warm (T~-1.6(C)Modified Weddell Deep Water (MWDW) occasionally is observed. The two current meters were anchored at 258m and 411m depth. At the mooring site the overall orientation of ice shelf was 310(and its thickness estimated to be near 200m. The Ronne Ice Shelf has its minimum thickness in the vicinity of the mooring station. The average direction of the currents was 290(at the upper meter and 275(at the lower meter. This indicates a steering of the flow by the ice shelf, but with a component of the flow towards it, indicating that water is penetrating underneath the floating ice shelf in the area. The MWDW was observed at 258m depth during the January - July. During the austral spring (August - December) the temperature was near the local surface freezing point (-1.9(C). At the lower meter (411m)MWDW was observed in May-June 1993 and also for about a week in the end of February 1994. Maximum salinities at the two levels were observed in September - November, salinities above 34.65 at the upper meter and occasionally exceeding 34.80 at the lower meter. This indicates that the saline Western Shelf Water was not produced locally, but probably at the Berkner shelf to the east. The major tidal component was M2, and surprisingly enough, the major axis of the current ellipses were near perpendicular to the orientation of the ice-shelf. Thus tides may play an important role for the heat exchange and melting in the area.

DECADAL-SCALE VARIABILITY OF PROPERTIES OF THE BASIN WATERS OF THE BRANSFIELD STRAIT (ANTARCTICA).

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Two mechanisms have been invoked as possible explanations for deep water mass formation in the Bransfield Strait: i) winter convection and ii) all-seasons lateral advection of a mixture of deep Weddell Sea and shelf waters. Recent field observations suggest that the deep Bransfield basin waters might in fact result from a combination of both mechanisms. Whereas local winter convection produces strong seasonal variation of properties of the Bransfield deep waters, deep water mass formation related to the inflow of Weddell Sea deep waters should reflect the interannual changes of properties of the source waters. CTD casts obtained at a number of deep stations in the central basin of the Bransfield Strait during the ISOS programme in the seventies, the BIOMASS cruises in the eighties and yearly since 1991 by the Spanish expeditions to Antartica are revisited to scrutinize for such interannual changes.

THREE-DIMENSIONAL CIRCULATION AND MASS TRANSPORT IN THE WESTERN BRANSFIELD STRAIT (ANTARCTICA) DURING AUSTRAL SUMMER

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R/V Hesperides occupied the western basin of the Bransfield Strait and the eastern sector of the Bellingshausen Sea in December 1995 and in January 1996. The horizontal geostrophic circulation patterns derived from the density fields display two main features: i) a meandering jet in the southern Drake Passage related to the Continental Water Boundary, i.e. the ACC southernmost front; ii) the Bransfield current, which appears as a northeastward recirculation of both waters with Weddell Sea influence flowing to the southwest along the Antarctic Peninsula shelf edge and a weaker inflow from the Drake Passage. Maximum horizontal speeds are of the order of 16 cm/s for both currents. The vertical velocity fields have been computed by integrating the quasi-geostrophic omega equation. Sensitivity of the circulation and mass transport estimates to the reference level and to the station distribution and spacing will be discussed. Our results indicate that the biological wealth observed at the northern sector of the study area in December (absent one month later) should not be attributed to frontal dynamic instabilities generating upward motion but to transient hydrographic conditions at the start of the Austral summer.

WESTERN WEDDELL OUTFLOW: THERMOHALINE STRATIFICATION

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As part of the DOVETAIL Program, an array of CTD, LADCP and tracer stations were obtained from the Palmer in August 1997 in the southern Scotia Sea and northern Weddell Sea. The data characterize the physical and chemical properties of the dense water outflow from the Weddell Sea and overflow into the Scotia Sea. The key results: 1. Warming of Weddell Deep Water observed during the last decades within the central Weddell gyre extends into the northwestern Weddell Sea. Warming in that region between 1992 and 1997 amounts to nearly 0.2°C. 2. Dovetail and 1992 Weddell Ice Station data define the distribution of the WSBW benthic layer in the western and northwestern Weddell Sea. The benthic layer takes on varied forms: thick well mixed; thin stratified; or a combination. The transition from thin to thick benthic layer may be aided by diminished thermobaric importance as mixing proceeds. 3. Within the Weddell-Scotia-Confluence there is well oxygenated, low salinity deep water, derived from the Antarctic Peninsula eastern shelf, which may directly ventilate the Scotia Sea. 4. The isolated basins of the Bransfield Straits contain well ventilated water. The cold end-member is similar to that of the WSBW, but with a much fresher warm end-member derived from the pycnocline water of the Bellingshausen Sea. The western Weddell continental margins form freezing point shelf water with a wide range of salinity that ventilates a thick segment of the deep ocean.

CHANGES IN THE CIRCULATION PATTERN AND WATER MASS CHARACTERISTICS OF THE FILCHNER TROUGH AS A (POSSIBLE) CONSEQUENCE OF ICEBERG CALVING

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One key area which influences the formation of bottom water in the southern Weddell Sea is strongly controlled by the flow of Ice Shelf Water (ISW) out of the Filchner-Ronne Ice Shelf cavity. Repeated hydrographic sections along the ice front gave an ISW-plume temperature colder than −2.3°C in the Filchner Trough in the early 1980s. The break-up of three giant icebergs in 1986 and their grounding on the shallow Berkner Bank changed the morphological setting of this region and with it the circulation and water mass formation. Hydrographic measurements in 1995 along the Filchner Ice Shelf edge show significant changes in water mass characteristics and flow pattern that influence the overflow at the continental sill. Although qualitative ideas of water mass modification and transport exist, a quantitative treatment of these processes is still missing. We combine a 3 dimensional ocean circulation model and CTD-measurements in a discussion of the circulation in the open ocean and beneath the ice shelf. The impact of iceberg calving on the circulation regime is investigated by both model results and measurements. The results depict sensitive areas where water mass modifications occur, for example High Salinity Shelf Water production on the shallow Berkner Bank as one source for ISW. A picture of the calving event as a paradigm for the sensitivity of the whole ice-shelf/ocean system is drawn.

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OCEAN CIRCULATION IN THE FILCHNER-RONNE ICE SHELF DOMAIN FROM 3D-MODELLING RESULTS

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The Filchner-Ronne Ice Shelf complex is the major source of Ice Shelf Water (ISW) in the Weddell Sea and, therefore, makes an important contribution to deep water formation. It comprises the second largest ice shelf by area in the Antarctic and represents with its interface to the ocean the biggest mass loss component by basal melting for the whole ice sheet. We present first results of a three-dimensional ocean model applied to the Filchner-Ronne Ice Shelf and the adjacent continental shelf area. The free interaction of the open ocean circulation and the ice shelf cavity across the ice shelf front yields the available heat transport that is responsible for the mass exchange at the ice shelf base and the corresponding fresh water flux to the ocean. The model offers the opportunity to study how changes in circulation and water mass properties on the shelf effect basal melting in the ice shelf cavity. The sensitivity to surface boundary conditions, sea ice processes, and open ocean boundary conditions can be i nvestigated with such a tool. The role of ISW for water mass formation on the continental shelf and the pathways from the ice shelf cavity to the deep Weddell Sea are important factors for the understanding of Weddell Seas deep water formation.

A MESOSCALE FRONTAL CYCLONIC EDDY IN THE ANTARCTIC CIRCUMPOLAR CURRENT

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The structure of currents, temperature and salinity fields of a frontal cyclonic eddy in the Antarctic Circumpolar Current and their evolution are studied on the basis of measurements made south of New Zealand. The analysis of the evolution of the eddy was studied on the basis of hydrographic data measured during two repeated surveys. The northeasterly propagation of the eddy into the area of warmer waters caused the intensification of the eddy which manifested in the sharpening of the fronts, increase of the available potential energy and growth of the orbital velocity of the currents. The eddy carries antarctic waters with a subsurface minimum of the temperature which is not characteristic to the surrounding waters north of the ACC. The waters with low salinity in the middle of the eddy correspond to the area south of the Polar Front. The temperature and salinity of the waters in the eddy best match the properties of the water at 60 degrees S, whereas the eddy was located at 57 S.

ROSSBY WAVEGUIDES IN POLAR SHEAR FLOWS WITH BOUNDARIES

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We study the propagation path and the structural change of quasi- geostrophic Rossby wave packets by means of a WKB-method whereby our approach involves the application of a rigid boundary, where the wave packets can be reflected elastically. We consider Rossby wave packet dynamics at high latitudes at the β-plane but also at the so called δ-surface, where the second derivative of the Coriolis parameter with respect to latitude is taken into account. We show that under certain conditions synoptic-scale wave packets can propagate far distances along an east-west oriented "coast" and may affect the flow far downstream of the source region. The wave packets considered here are trapped between a turning latitude and the reflecting boundary. We investigate this Rossby waveguide also by means of a barotropic β-plane channel with reflective walls. Preliminary results are shown. Finally we suggest that a selective Rossby wave guide of the type described here may play a role in the dynamics of the Antarctic Circumpolar Current.

TIDAL RESIDUAL CURRENTS: THEIR CONTRIBUTION TO OCEAN CIRCULATION BENEATH FILCHNER-RONNE ICE SHELF.

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The ocean beneath an Antarctic ice shelf is isolated from atmospheric forcing, such as wind. The ventilation of the sub-ice shelf cavity will be dominated by tidal and thermohaline driven circulations. The extent to which tidally driven circulations, ventilate the cavity beneath Filchner-Ronne Ice Shelf is largely unknown. Applying a depth averaged tidal model to the southern Weddell Sea, including the ocean cavity beneath Filchner-Ronne Ice Shelf, it was found that tidal oscillations with velocities up to 1 m s-1, generate significant residual currents in areas with shallow water and large topographic gradients. The model indicates that Lagrangian residual currents transport water at fluxes of up to 250,000 m3 s-1, and at speeds of over 5 cm s-1 along the ice front, with over 350,000 m3 s-1 being exchanged between the sub-ice shelf cavity and the adjacent continental shelf. These currents are particularly efficient in ventilating the sub-ice shelf cavity within 150 km of Ronne Ice Front. Shipborne hydrographic observations along the ice front support many of the model predictions concerning the capacity for residual currents to transport water masses between sub-ice shelf cavity and open sea.

THE INFLUENCE OF ICE SHELVES ON WEDDELL SEA WATERS

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The Weddell Sea is considered to be a major source of waters participating in the global thermohaline circulation. The water masses are formed by a number of processes at different high-latitude locations including the bases of large ice shelves in the Weddell Sea. The meltwater plumes emerging from the Filchner and Ronne subice cavities are assumed to participate in the bottom water formation process at the continental slope. However, due to its warmer temperatures, plumes from the Ronne and also Larsen Ice Shelves might be more involved in the deep water formation processs along the western Weddell rim. Therefore, these plumes might have a more direct influence on global abyssal waters. The influence of the ice shelves in the eastern Weddell Sea is considered to be minor, but a pre-conditioning of the water masses entering the Weddell Sea and flowing south towards the southern continental shelf seems likely. Preliminary model results also suggest a control of the eastern Weddell Ice Shelves on the strength of the coastal current. We test these sensitivities by applying a high resolution (~20 km), sigma coordinate primitive equation model (SPEM) to the Weddell Sea, embedded in a coarse resolved Southern Ocean, which includes the subice shelf cavities and the processes acting at the ocean/ice interface. Model runs which include different subice environments, are used to quantify the importance of the cryosphere for Weddell Sea's circulation, water mass characteristics and deep and bottom water formation.

SPATIAL/TEMPORAL PATTERNS IN WEDDELL GYRE CHARACTERISTICS AND THEIR RELATIONSHIP TO GLOBAL CLIMATE

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A set of parameters that impose controls or limitations on the sea ice distribution, ocean vertical heat flux and ocean bulk stability have been computed for the Weddell gyre region. These parameters are derived from a set of scalings that involve vertical distributions of temperature and salinity in the upper water column. They provide seasonally-averaged information on: (1) the maximum amount of *in situ* ice growth in any one location, (2) the ratio of ice melt to ice growth, (3) the amount of ice that has melted in any particular summer location, and (4) the ocean winter-averaged heat flux. Climatological maps of these parameters are presented for the Weddell gyre region. These show coherent spatial patterns, many reflecting the gyre structure. An EOF analysis is used to investigate the temporal variability of these patterns. This involves an optimal interpolation of the observations which have been sporadically collected in space and time over the last 25 years. The temporal variability of the dominant structure is correlated to standard extra-polar climate indices and to variations in the sea ice edge (also tied to global climate indices). This study shows strong lagged correlations between some of the parameters and the El-Nino - Southern Oscillation (ENSO) index (and other indices), with the magnitude of the temporal lag displaying a spatially-varying pattern consistent with the gyre structure.

DEEP OCEAN VENTILATION THROUGH ANTARCTIC INTERMEDIATE WATERS: THE DOVETAIL PROGRAM

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The goal of the international program for study of Deep Ocean VEntilation Through Antarctic Intermediate Layers (DOVETAIL) is to understand physical processes in the Weddell-Scotia Confluence (WSC) region sufficiently to quantify the ventilation of the World Ocean achieved by Weddell Sea water masses. There are four related objectives, the first being to assess the quantity, physical and chemical characteristics of Weddell Sea source waters for the WSC. The second objective is to describe the dominant physical processes associated with spreading and sinking of dense Antarctic waters within the WSC region. The third is to estimate the ventilation rate of the World Ocean from the Weddell Sea. The final objective is to estimate seasonal fluctuations in regional ocean transport and hydrographic structure, and assess the likely influence of interannual variability on rates of ventilation by Weddell Sea waters. These objectives are approached through integrated field measurements and numerical modelling. Two field programs have taken place to date. During the first, in March 1996, the German vessel *Polarstern* deployed six long-term moorings off the Antarctic Peninsula in a joint German/Spanish effort. During the second, in August 1997, the U.S. vessel *Palmer* carried out extensive water property and current measurements in the WSC region and deployed an additional 11 current moorings. Data will be recovered from the moorings during 1998 and into 1999.

3D MESOSCALE CIRCULATION AT THE ANTARCTIC POLAR FRONT - IMPACTS ON PRIMARY PRODUCTION.

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Analysis of data collected during a mesoscale 3D survey of an Antarctic Polar Front (APF) meander near 10 E, 50 S using a towed undulator (Seasoar), a vessel-mounted Acoustic Doppler Current Profiler and a moored current meter is utilised to test the hypothesis that the cross-front circulation resulting from baroclinic instability fosters primary production at the APF. During frontogenetic events, such as the one encountered in our survey, a generally southward ageostrophic flow near the surface (calculated as ~ 1 cm/s from semigeostrophic (SG) balance) tends to stabilise the upper water column by causing light water from the north to overlay denser water from the south, hence creating a more favourable photic environment for phytoplankton growth in the mixed layer. The associated mesoscale upwelling in the northern side of the APF (inferred to be ~ 5 m/day by use of the SG Omega Equation) is also able to replenish the photic zone with nutrients or trace elements which could otherwise limit production. This circulation pattern poses a significant constraint to the distribution of nutrients in the Southern Ocean: firstly, by opposing the northward Ekman transport of nutrients upwelled in the Antarctic Divergence to the south; and secondly, by enhancing nutrient uptake rates in parallel to primary production, with possibly an intensified biologically-mediated vertical particle flux. The observed sharpening of the meridional gradient of silica concentration at the APF might be interpreted in terms of these two processes.

A GLOBAL OCEAN-SEA ICE COUPLED MODEL : RESULTS FOR ANTARCTIC SEAS

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A dynamic and thermodynamic sea ice model, ICESTATE, has been developped in NERSC and CNRM from 1996. The model was primarily aimed at describing mesoscale processes, but it can also be used on the large scale. We focus on results around the Antarctic in the present study.
First, the model was just forced by meteorological and ocean data, and the inclusion of sea ice dynamics showed significant improvements in sea ice extent and concentration. Also, the ice edge was well positionned at any time of the year. In addition to this control experiment, sensitivity studies were performed. ICESTATE turned out to be moderately sentitive to temperature changes, but not so much to cloud fraction variations, because they had opposed effects on long and short wave incoming solar radiations. Second, ICESTATE was run in coupled mode; again it can be emphasized that the implementation of sea ice dynamics contributed strongly to yield much better results than the previous thermodynamic-only version.

SPREADING OF WATER MASSES FORMED IN THE WEDDELL SEA

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Water masses newly formed in the Weddell Sea participate in the global thermohaline circulation. Depending on the formation process and its location along the Weddell Sea periphery, these water masses follow different routes, which do not always allow a direct escape from the Weddell Basin, surrounded to the north by a ridge with sill depths of 3000 m. Recent field experiments (ISW-1 and DOVETAIL) show that water masses formed along the western Weddell continental slope can pass northern sills to form the bottom waters of the Scotia Sea from where further spreading to the north is possible. Water masses carrying the meltwater from the Filchner-Ronne Ice Shelves sink and flow at greater depth allowing an escape only in the eastern Weddell Sea. However, the observations are limited in space and time possibly leaving further escape-routes still undiscovered. We investigate the routes and transports of newly formed waters by "deploying" Lagrangian floats at different locations in a terrain-following, primitive equation model (SPEM) for the Southern Ocean south of 50S with higher resolution (~20 km) in the Weddell Sea. The deployment locations are the northern sills of the Filchner and Ronne Depressions on the southern Weddell Sea continental slope.

ANTARCTIC CURRENTS IN HIGH-RESOLUTION OCEAN AND CLIMATE MODELS

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Results from two ocean models are used to improve understanding of ocean circulation in the ice-covered seas around Antarctica. Primitive-equation free-surface thermohaline models were coupled to Hibler ice models. Each model is global but has high polar resolution resulting from a mercator grid finer than 20 km (or 50 km) south of 60°S and from 20 (or 32) levels. The first model was run 40 years from Levitus initial conditions, using ECMWF wind stress and heat flux with surface salinity restoring. The second model was run 95 years from Levitus using repeated 5-year atmospheric forcing from NCAR's latest Community Climate Model without restoring; and deep water was accelerated out to 500 years. The first model better depicts the narrow coastal currents around Antarctica and the mesoscale eddies and filaments further offshore, while the second model better depicts deep circulations such as the outflow from the Weddell and Ross Seas and their connections to the global thermohaline circulation. Together, the models provide a view of Antarctic circulation that matches and extends much of the available knowledge from observations. The overall circulations are quantified in terms of the transports of mass, heat, and salt, as well as the surface forcings. Another paper by Zhang and Semtner discusses connections of the upper ocean to the sea ice, with particular emphasis on heat and salt fluxes and advection and convection under ice and in polynyas.

SEASONAL VARIABILITY OF SEA ICE IN A COUPLED ICE-OCEAN MODEL FOCUSSED ON THE WEDDELL SEA

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Seasonal variations of the sea ice cover in the Southern Ocean represent one of the most pronounced signals in the annual cycle of the world climate system. The freezing and melting of sea ice controls the amount and location of deep and bottom water formation in the Weddell Sea which is a major source of the bottom water of the world ocean. Part of the BRIOS (Bremerhaven Regional Ice-Ocean Simulations) project aims at an improved numerical simulation of the ice-ocean system in this area, and specifically at a quantitive description of the interplay between sea ice, ocean currents and local topography. The model consists of a dynamic-thermodynamic sea ice-model with viscous-plastic rheology (based on Hibler/Lemke) coupled to a sigma-coordinate primitive equation ocean model (SPEM). The ocean model includes the thermohaline forcing in the cavities beneath the Antarctic ice shelves. Model runs are initialized using the Southern Ocean Atlas and forced with wind, cloudiness and temperature fields of the ECMWF 6h-analyses. The annual cylce is realistically reproduced by the coupled model, the sea ice distribution is in close agreement with SSM/I observations. Winter sea ice thickness compares well with drill hole measurements and with data of upward looking sonars (ULS). The main ocean surface current turns out to be generally important for the advection of ice but particularly for the horizontal advection of heat during the melting season in the southern Weddell Sea. Parameter studies show sensitivity to prescribed precipitation and sub-grid scale / mixed layer parameterization in the ocean model.

FLUORIDE SOURCES AND DISTRIBUTION AT NORTHERN VICTORIA LAND (ANTARCTICA)

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The first effective distribution data of fluoride in the Region Northern Victoria Land (Antarctica) are reported here. An Ion Chromatographic method for the determination of this component was applied to four snow pits, a 22 m (63 years) firn-core and a 120 m (about 700 years) firn-core; the four sampling stations differ for altitude and distance from the sea. As regard as fluoride concentration, mean winter values are higher than summer values for the three stations at lower altitudes; for the highest station, summer and winter mean values are coincident. The comparison between concentration/depth profiles of fluoride and sea spray markers with the analysis of the correlation between F- and Na+ concentrations for marine events shows an evident oceanic source and contemporaneous fractionating effects. Volcanic emissions are another sporadic source of fluoride: we found a typical volcanic event located at about 90 m depth (about 450 years ago) demonstrated by the concentration increase of volcanic emissions typical markers. The temporal concentration/depth profile of a 22 m firn-core shows a long term biomass-burning event demonstrated by the contemporaneous concentration increase of fluoride, carboxylic acids, potassium, ammonium and from a very high dust content. Moreover, higher concentrations of fluoride found in the period of Antarctic air mass stratosphere-troposphere exchange and an increase of concentration peaks number in the eightys respect to the previous and following period, make CFC another possible source of fluoride.

RESPONSE OF THE WEDDELL SEA ICE PACK TO WIND FORCING

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Seven buoys were deployed on sea-ice floes in the central Weddell Sea in January-February 1996 during the FINNARP-96 expedition, which followed the FINNARP-89 and 92 expeditions. Two buoys had a meteorological mast, two were equipped with air pressure sensors and the remaining three transmitted location data only. Six buoys formed an array with initial mutual distances of 50 km, which were stretched to around 400 km in East-West direction by October 1996. Meteorological data of ECMWF analysis fields were interpolated at the buoy sites and compared with the buoy observations. Wind influence on the buoy drift was studied by assuming a simple linear wind-drift relationship corresponding to the free-drift conditions. Wind is the primary forcing factor of the ice motion in the Weddell Sea. The correlation coefficient (r) between the wind and the drift velocities was high (0.85). The drift correlated with the geostrophic wind (r=0.75), but not significantly with the ECMWF ten metre winds (r=0.4). The air-sea-ice heat exchange and atmospheric stratification and their interaction with the ice dynamics were studied. The differential kinematic parameters of the drift were calculated from the buoy array. Large scale drift was divergent, $(5.5\pm1.9)\times10^{-8}s^{-1}$, but periods of convergence were apparent as well, and the standard deviation of the divergence was one magnitude greater than the mean value. The large scale vorticity corresponded the clockwise motion of the Weddell Gyre and the shearing rate represented mainly deformation due to zonal velocity gradients. Major features of negative vorticity and the shearing deformation occurred when low-pressure systems passed over the buoy array.

DIRECT VELOCITY MEASUREMENTS RELATED TO WESTERN WEDDELL OUTFLOW: TRANSPORTS AND MIXING

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As part of the international DOVETAIL Program, an array of CTD with LADCP stations were obtained from the N. B. Palmer in August and September 1997. The LADCP velocity measurements showed new aspects of the circulation within the Weddell - Scotia Sea confluence region:

1) At several stations we found eastward flowing bottom intensified currents south of the South Orkney Islands with velocities exceeding 10-20 cm/s. These flows are strongly affected by the local bathymetry, carry newly ventialted Weddell Sea Bottom Water (WSBW) and would be excellent sites for longterm moored observations.

2) The total eastward transport of the Weddell gyre was about 50 Sv measured along sections at 45°W and 40°W. The transport for all layers with a temperature below 0°C was about 40 Sv and 10 Sv for layers colder than -0.5°C.

3) North of the South Orkney Island we found a deep westward flowing boundary current with velocities exceeding 20 cm/s and Weddell Deep Water mass signatures.

4) Bulk Richardson number calculations allowed us to identify regions of large diapycnal mixing over rough topography and near the boundary currents. These regions of elevated deep mixing are important since they allow WSBW to mix upward and thereby ventilate the Weddell Deep Water (WDW).

SEA ICE PROPERTIES AT THE ANTARCTIC WINTER ICE EDGE FROM ERS-2 SAR IMAGERY

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The Antarctic winter ice edge region has been investigated by only a small number of ship cruises, and has not hitherto been accessible to remote sensing by synthetic aperture radar (SAR) because Antarctic receiving stations have been summer-only.On July 4 1997 the German receiving station at O'Higgins, Antarctic Peninsula, carried out a short-term winter experiment in which a swathe of 21 images was obtained covering a transect of the Antarctic ice cover from the South Sandwich Islands into the Weddell Sea. The images covering the ice edge (at about 59°S, 29°W) show a structure of frazil ice bands, transforming into pancake ice and finally into consolidated first-year ice, a sequence first observed by "Polarstern" in 1986. By using a novel cross-spectral technique to analyse the change in the wave number of ocean waves entering the ice, we were able to estimate the thickness of the ice in the frazil and pancake areas, and also obtain the wave spectrum at the point where the pancakes froze together to form a continuous cover. The distance to which detectable wave energy penetrated was measured. From the remainder of the 21 images we were able to estimate the total ice concentration and the iceberg density as functions of latitude, and the regions in which substantial concentrations of multi-year ice could be found.

OCEAN-ICE INTERACTION WITHIN THE WEDDELL AND COSMONAUT SEAS FROM HIGH-RESOLUTION MODELS

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Outputs from two coupled ocean-ice models are analyzed and compared to study Antarctic ocean and ice interaction. The sea ice models are based on Hibler's dynamic-thermodynamic model. One of the ocean models is the Semtner-Chervin 1/4° on average, 20-level global model, and the other is the Los Alamos Parallel Ocean Program (POP) with 2/3° on average, 32 levels. Both models have much smaller horizontal grid sizes in polar regions. ECMWF and CCM3 winds and heat fluxes are used to drive the Semtner-Chervin model and the POP, respectively. More descriptions of the models can be found in another paper by Semtner and Zhang, which discusses Southern Ocean general circulations. Large spatial and temporal variations of under-ice oceanic heat flux is present in the models with maxima located in the eastern Weddell Sea, the Cosmonaut Sea, and near Maud Rise in winter. These are regions where recurring polynyas are observed and simulated. Effects of ocean eddies and upwelling on under-ice oceanic heat flux and the occurrence of polynyas are investigated. Upwelling is induced both by large scale circulation and topographic effects. Quantitative analyses of the influence of ice growth/melt and associated salt flux on the salinity of shelf water and the upper ocean are shown. The impact of heat and salt fluxes on static stability of the water column, and thus convection, is discussed.

OA8 The Mediterranean Sea: general circulation variability and related processes

Convener: Pinardi, N.
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HYDROLOGICAL CHARACTERISTICS OF THE LIW IN LONG INTEGRATED OGCM EXPERIMENTS

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The assessement of the capability of representing the present day circulation in long integrated experiments is the first task in order to perform climatic studies with OGCM. In particular, the right determination of the water masses hydrological characteristics is a crucial factor for the representation of thermohaline circulation in the Mediterranean Sea, where mixing phenomena between water masses formed in connected evaporative sub basins play an important role in the determination of the circulation.
In this work we focus our attention on the main feature of the thermohaline circulation of the Mediterranean sea: the formation and spreading of the Levantine Intermediate Water (LIW). We introduce new parameterization both of the surface tracer restoring terms and of the tracer diffusivity coefficient and we force the model with high space and time resolution data set for wind stress and SST (ECWMF wind, and satellite SST, respectively). As a result we obtain that the previously observed warming of the LIW is eliminated and the correct hydrological values the Mediterranean water masses and the right energetic balance are obtained. A hierarchy of numerical experiments is presented in order to determine the relative importance of the new parameterisations and boundary conditions we have introduced.

A NUMERICAL STUDY OF THE GIBRALTAR STRAIT.

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The Strait of Gibraltar is a narrow and shallow channel between the Atlantic Ocean and the Mediterranean Sea with an internal hydraulic jump to the west of the sill and a two-layer inverse estuarine circulation. We tried to understand the role of the Strait of Gibraltar in the circulation of the Mediterranean with a direct numerical simulation approach. The numerical simulation was performed using GWEM (Gibraltar Water Exchange Model), based on the POM (a primitive equation, time-dependent, free surface, split mode time-step model with Boussinesq and the hydrostatic approximation). The computational domain (18°W to 3°E and 30°N to 42°N) uses a horizontal curvilinear orthogonal grid (120x60 elements) with variable grid resolution (1.5 Km $\rightarrow$ 50 Km). Along the vertical a 21-level sigma-coordinate system is used, shaped on a realistic bathymetry. The starting fields of temperature and salinity are the July Levitus 94 data, interpolated bi-linearly in the horizontal and linearly in the vertical while the starting velocity field is null. The momentum flux at the surface and the wind stress components are not yet considered. The GWEM has two lateral (east and west) sponge boundary layers in order to prevent wave reflections and to restore the ocean density to the monthly condition through a Newtonian relaxation. Initially this model was used to perform simulations suitable for defining the locations of subcritical , critical and supercritical flow in stationary conditions; then tidal effects are added to find the new critical Froude number locations.

MODELLING OF THE COASTAL OCEAN CIRCULATION IN THE NORTH-WESTERN MEDITERRANEAN SEA: METHOD AND RESULTS

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In the last decade, oceanographic models have quickly evolved toward a realistic description of the general circulation of the Mediterranean. However, computational costs remain prohibitive as soon as we are interested in small scale informations. A straightforward solution is then to model only the most salient part of the the basin using a small scale grid and a well adapted free-surface coastal model. Such an approach raises the problem of the specification of the general circulation: the initialization and the choice of the boundary conditions. We developed an original approach based on inverse technics. Data originating from in-situ observations and/or general circulation models are optimally interpolated over the small scale grid in such a way that they do agree with the physics of the free surface model Symphonie. A case of particular interest we shall focus on, is the study of the interaction of the west-Mediterranean general circulation with the topography of the continental shelf of the Gulf of Lions.

COMPARATIVE STUDIES BETWEEN RESULTS FROM BOX MODELS AND OGCMS APPLIED TO THE MEDITERRANEAN SEA

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A comparison between results from an OGCM (MOM) and a box model applied to the mediterranean circulation is performed. The box model consists in three vertical boxes connected to the Atlantic through an inflow in the middle box and an outflow from the lower box. Mixing is parameterized in terms of two vertical diffusion coefficient and the convective events are represented by an infinite vertical diffusion when static instability occurs.
This simple model is able to represents the thermodynamics of an evaporative basin and when applied to the mediterranean case the comaparison with the results from a realistic model is satisfying. Consequently we consider this box model as an handling and useful tool in order to isolate both the main mechanisms of the mediterranean circulation and to test the impact of particular physical phenomena. In particular we show that this kind of comparison can be useful in order to rationalize the relation between surface boundary condition, vertical diffusivity and convective events. Moreover we test in the box model the impact of the physics of the Straits in the general circulation introducing the hydraulic control through the overmixing theory. The resulting more effective mixing in the basin indicates the active role played by the straits in the general circulation and can be useful for parameterizing it in a OGCM.

ANALYSIS OF FLOW AND TRANSPORT MEASUREMENTS IN THE STRAIT OF GIBRALTAR

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During the pilot phase for the EC-Project CANIGO, moored current meters were deployed in the eastern entrance of the Strait of Gibraltar and at the sill from Oct. '95 to Apr. '96. Additionally ship-board flow observations were obtained during two CANIGO cruises in Apr. '96 and Oct. '97. A combined analysis of ship-borne and moored measurements is presented which aims at improving the description and understanding of the temporal and spatial structure of flow in the Strait. With this a suitable sampling strategy for future measurements can be designed. It also helps to improve estimates of mass transport through the Strait from past and future data sets.

GAS TRANSFER PARAMETRIZATION IN THE WESTERN MEDITERRANEAN

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An one dimensional mixed layer model representing the Gulfe du Lion is driven by three different meteorological data sets: (1) METEO, based on the weather stations Pomégues and Cap Bear, (2) COADS, and (3) ECMWF. Included in the model are three air-sea gas transfer parametrizations. The influence of the meteorological forcing and the gas transfer on the vertical chlorofluorocarbon (CFC) distribution, components CFC-11 and CFC-12, is discussed for a period of one year fom Dec. 1991 to Dec. 1992. The modeled CFC profiles are compared with observations made on the RV Valdivia cruise 118 in spring 1992. It turns out that only the METEO forcing produces observed mixed layer depths. For the gas transfer parametrization, only the formulation of Liss and Merlivat led to model CFC profiles comparable to measurements.

THE RESPONSE OF THE ADRIATIC SEA TO AN IDEALISED TRAVELING STORM

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The response of the Adriatic Sea to an idealised traveling storm is studied using a simple storm surge numerical model. Most of the research on the wind driven currents in the Adriatic Sea concentrated on steady response. Recent results by Orlić et al. (1994) show the character of steady barotropic response to both bora and sirocco forcing. Bergamasco and Gačić (1996) extended the results of this analysis by considering the response of the stratified Adriatic Sea to and episode of bora wind. The observations, however, show interesting transient features associated with both winds.
Both bora, a norhteastern wind, and sirocco, a southeastern wind, represent transient phenomena and are related to migrating cyclonic systems that propagate over the Adriatic. Therefore, a model of an idealised storm is used here to study the transient response in currents and sea level. The analysis concentrates on the northern part of the Adriatic where long-term observations of sea level and currents are available for comparison against the model predictions. Model predicted currents and sea level are analysed using complex empirical orthogonal functions. The results suggest that the transient response of the Adriatic Sea strongly depends on the propagation speed of the storm as well as its track.

RESULTS OF THE MEDITERRANEAN MODELS EVALUATION EXPERIMENT (MEDMEX)

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The aim of the present work was to achieve an intercomparison of the existing models which are currently applied to the Mediterranean Sea.
A relatively complex model test situation was chosen: the realistic situation found in the Mediterranean circulation, were two experiments were initiated.
The models participating in the intercomparison (MOM, POM, GHER, OPA, MOMb) all used the same horizontal grid (1/4°), 31 vertical degree of freedoms, as well as the same external forcings.
The first experiment was based on robust climatological perpetual year approach, in which atmospheric forcings were monthly averaged wind stress fields and SST/SSS values for surface relaxation of the density field.
The second experiment used daily wind stress and heat fluxes instead.
The presentation of the results will present the general model agreements on circulation patterns and fluxes through straits and show the different model's drift for the different forcings.
Some tentative explanations of the difference in the model behaviour will be given, specially with regard to the vertical exchange parameterisations.

DECADAL AND INTERANNUAL VARIABILITY IN THE MEDITERRANEAN SEA: MODEL SIMULATIONS AND OBSERVATIONS

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A general circulation ocean model of the Mediterranean Sea (1/4 of a degree horizontal resolution and 31 levels) has been used to simulate the decadal and interannual variability of the flow field from 1946 to 1993. Surface forcing is given by COADS (Da Silva et al., 1995) heat and momentum fluxes while sea surface salinity is restored to climatological monthly mean values. Heat flux corrections are applied to impose a balance between heat advection at Gibraltar and heat flux at the basin air-sea interface, using COADS sea surface temperature fields. The MODB historical data base has been analyzed to provide the comparison data set to validate the model response. Four regions, like the Gulf of Lions, the Tyrrhenian, the Northern Ionian and the Rhodes Gyre area have been analyzed with advanced statistical methods in order to produce time series of sea surface temperature and heat content for the same years of the model integration. The model and historical data are then intercompared as well as spectra of relevant time scales of variability for both model and observational data sets. Further comparison of quasi-synoptic data sets with model simulations is done in order to assess the quality of the model dynamical response.

COMPARISON OF VERTICAL PROJECTION SCHEMES APPLIED TO DATA ASSIMILATION IN THE MEDITERRANEAN

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The main aim of this work is the assimilation of altimetric data into a primitive equation numerical model for the Mediterranean Sea. The Mediterranean model is run with two resolutions: $\frac{1}{4}$°, 19 levels and $\frac{1}{8}$°, 31 levels. We start by making a climatological run in order to have a steady initial state for the subsequent runs. We then use high-frequency, realistic atmospheric forcings from ECMWF (European Center for Medium-Range Weather Forecast) for a two year run 1992-93. We then use an optimal interpolation technique to assimilate TOPEX-POSEIDON altimetric data over the same period. Three different vertical projection schemes are compared: a statistical method based on vertical empirical modes, The Gavart and De Mey(1997) isopycnal modes and The Cooper and Haines(1996) method. The vertical modes are calculated from model statistics during 1993, with ECMWF forcing. The assimilation results show that the $\frac{1}{4}$° resolution MOM model has the ability to produce realistic circulation with some predictive capabilities in the 7-14 days range. Sensitivity studies have also been carried out : in particular to study the influence of ERS-1 data on the assimilation, the choice of statistical parameters, the localisation of empirical modes, the use of a smoother mode and the choice of forcing functions.

SOME FEATURES OF THE VERTICAL CIRCULATION IN THE BLACK SEA

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Methods of calculation of the vertical current component profiles w(z) on the basis of the statistical method of the maximal verisimilitude are created for analysis of the vertical circulation characteristics. The data of survey of the density and currents fields in the North-Western Black Sea were used for this purpose. Following results are received on the base of executed accounts. 1. Vertical circulation in kind of two cells with opposite character of rotation and with layer of zero speeds in central piknokline part was observed in the region of the Main Black Sea Rim Current. Maximal significances w(z) are equal from 1 to 4 m/day. Such structure of the vertical circulation corresponds to the hydrodinamical model of the formations of the currents fields and stratification in the Black Sea under action of the buoancy flows (Bulgakov,Korotaev,1984; Bulgakov,Korotaev,Whitehead,1996; Bulgakov,1996). 2. Vertical circulation renders the specific influence on the optical and chemical characteristic: the turbidity extremum is increased in 2.5 times in w=0 layers in comparison with background conditions; significant intensity of the phosphate and nitrate extremums are observed in this layer also.

ON DENSE WATER FORMATION CRITERIA AND THEIR APPLICATION TO THE MEDITERRANEAN SEA.

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In this note, recently proposed criteria to identify sites, periods and characteristics of dense water formation in the Mediterranean basin are analyzed. These criteria were first obtained through tank experiments (Narimousa and Maxworthy, 1994; Narimousa, 1996) and numerical and theoretical studies (Visbeck, Marshall, Jones, 1996 and Tzipperman, 1986); they can be useful to discriminate between the processes that reach the sea bottom and those interesting only a less thick superficial layer. Using these criteria, general characteristics of dense marine water can be inferred from the knowledge of winter sea stratification g', of the sea buoyancy increase B, as due to the violent winter storms at study, and the space scale R of the region interested, usually identified by a decrease of $0,5-1°C$ of the SST. For the Mediterranean sea, these criteria are here applied to the few known field observations, as well as to more indirect "routine" information as climatological values of the stratification, numerical estimates of the buoyancy flux and remotely sensed SST from satellite imagery. In this way a stimulating picture of these dramatic phenomena is obtained, giving some insight on the possibility of forecasting in real time sites periods and also other general characteristics of dense water formation processes.

NUMERICAL SIMULATIONS OF THE MEDITERRANEAN GENERAL CIRCULATION FOR THE PERIOD 1979-1993

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A long-term numerical simulation (15 years) with an Ocean General Circulation Model (OGCM), a modified GDF-MOM1, are carried on to analyze the interannual variability of the circulation (velocity and dynamic height) and water-mass formation processes for the period 1979-1993 in the Mediterranean Sea. The model, with 31 levels and 0.25 degree of horizontal resolution, is forced by momentum fluxes (wind stress) and heat fluxes (with all the surface heat budget components) at the surface. The atmospheric forcing are the 6-hourly ECMWF re-analysis surface fields (wind velocity, air temperature and relative humidity) and the UWM-COADS cloud cover data. The Western Mediterranean Deep Water (WMDW), the Eastern Mediterranean Deep Water (EMWD), consisting of Adriatic and Aegean water, Levantine Intermediate Water (LIW) and Levantine Deep Water (LDW) are analyzed in their areas of formation in different ways (vertical sections and formation rates). The climatic event of an intrusion of Aegean deep water in the bottom water of the Eastern Mediterranean since 1988 has been detected and analyzed.

BOX MODELS OF THE MEDITERRANEAN SEA AND MULTIPLE EQUILIBRIA OF THE THERMOHALINE CIRCULATION.

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Box models allow a good qualitative description of phenomena which affect thermohaline circulation, such as multiple equilibria or oscillations.
A very simple model of the Mediterranean sea, with 3 vertically homogeneous boxes, is formulated considering that the role of salinity is preponderant in driving the circulation. Climatological forcing is simply modelled by a Newtonian restoring law. This modeling approach is equivalent to solve a non-linear dynamics systems whose control parameters are linked to climatology.
Different climatological situations have been investigated. It is found that under present conditions, there is one main stable circulation cell. On the other hand, under paleoclimatological conditions, the model leads to multiple equilibria, which result from the competition between saline and thermal effects. The different equilibria are displayed by describing circulation cells and fluxes at Gibraltar's and Sicilian's straights.

INTERANNUAL AND SEASONAL VARIABILITY OF THE MEDITERRANEAN ECOSYSTEM. A NUMERICAL STUDY.

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The relative importance of interannual and seasonal scales in the variability of the biomass is addressed using MOM-NPD+, a three-dimensional hydrodynamical ecological model developed for the Mediterranean within MATER project. The variability in the physical forcings has been recognized as a major component of the variability of the upper ocean circulation which in turns affects the ecosystem dynamics, in particular where nutrients control the growth rate of primary producers. The seasonal variability is the main signal of ecosystem cycle where the mixed layer deepening triggers the events that create the nutrient pools in the euphotic zone. Convective episodes increment the entrainment of nutrients in the surface layer. The interanual variability in the euphotic zone is mainly dependent on the concomitant variability in the wind stress, while light and temperature appear not so relevant. The 'anomalous' 1981 and 1986 winter winds, as reproduced in NMC monthly mean data set, generate an increment in the autotrophic biomass. Quantitative assessment of the relative importance of forcings in time and in the subbasins strongly support the different response in the eastern and western subbasins.

COMPARATIVE ANALYSIS OF SST INTERANNUAL VARIABILITY IN THE WEST MEDITERRANEAN SEA AND NORTH-EAST ATLANTIC OCEAN

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Mean SST time series (1982-1992) for the entire West Mediterranean Sea have been compared with ones for the Sicilian upwelling region, the Ligurian Sea and NE Atlantic Ocean (5-45N and 25W - coast of Africa and Europe). The analysis revealed not only a similar definitive rise of temperature by 1-2C since 1982 till 1987, but a similarity in the form of interannual seasonal cycles. The Sicilian upwelling summer SST rised by 5C due to additional decreasing trend of the wind (upwelling favorable wind stress) over the West Mediterranean Sea, resulting in a corresponding diminution of the upwelling intensity. 1988-1992 time period showed notable differences basically in winter SST trends.

TRANSPORTS IN EASTERN MEDITERRANEAN DURING WINTER 1995

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Using CTD data collected during the January 1995 Meteor cruise in Eastern Mediterranean, transports across four meridional sections are estimated. The sections consist of one covering the Ionian Sea, two sections west and east of Crete and one section west of Cyprus. Density and geostrophic flow are estimated assuming initial reference level at 500 dbar. In order to determine an adjustment factor for the geostrophic shear, ADCP data are also incorporated in the analysis. The density field is split into five selected isopycnal layers and the transport in each layer is calculated demanding the net value across each section to be zero, with the exception of the section east of Crete where it is adjusted to account for the 1.2 Sv of westward transport of the Asian Minor current. No constraint on the volume transport of each layer is applied, as between the sections water mass formation is probably taking place. The major pattern is water going wetsward at the surface layer in all sections and returning at deeper layers. The size of the overturning is of the order of 1.5 Sv. The resulting salt balance insdicates that there is divergence of salt transport away from the Levantine region. This in turn implies strong evaporation in the same region. The associated heat transport indicates that heat in the deeper layers is carried away from the Levantine. This feature is consistent with downwelling in the region.

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ISOPYCNAL MEDITERRANEAN DATA ANALYSIS AND SEASONAL VARIABILITY OF THE OUTCROPING

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The isopycnal treatment has recently received a great deal of interest by oceanographers, because the isopycnal representation of spatial features can be very helpful in the interpretation of observed dynamical features and localization and analysis of the outcroping zones. It is well known that observing and understanding the outcroping allow a better knowledge of the mechanisms controlling the ventilation phenomenon and its variability, because the ventilation occur generally along the outcroping areas. In the absence of diabatic processes, the stable stratification of the ocean constrains fluid motion to be nearly along surfaces of constant potential density. The aim of this study is to implement a new tool based on the cross validation technique and parameter optimization of Brankart and Brasseur (GHER) in order to reproduce the 3D hydrographic fields in the isopycnal coordinates (as part of the MATER project). From the preliminary results, we can observe the seasonal and spatial variation of the outcroping. The oucroping zones are generally concentrate in the eastern region, the Adriatic Sea and the northern part of the western region. This characteristics influence the ventilation system and the circulation in all Mediterranean Sea.

A VERY HIGH RESOLUTION MODEL OF THE CIRCULATION OF THE MEDITERRANEAN SEA

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Building an eddy resolving circulation model of the Mediterranean Sea faces two main problems : relatively small dynamical scales (e.g. Rossby radius) and very complex topography features (several straits and sills, narrow shelves, ...). A model grid must accurately take into account these two constraints. We have computed the first and the second Rossby radius from the MODB data base for all seasons. The first Rossby radius ranges from 15 km in Alboran to 10 km in most areas and much less in winter, while the second Rossby has a mean value of around 3 km. Based on these scales, a grid for the whole basin with variable resolution of at least 7km has been built. This grid is exactly connected to the grid of the french $\frac{1}{12}^{\circ}$ model of the North Atlantic. The topography is derived from the International Bathymetric Chart of the Mediterranean. The model is based on the OPA code, a three-dimensional primitive equations numerical model running on a Massively Parallel Processor machine. A first academic experiment has been performed on this high resolution and with realistic topography. It shows that coastal currents exhibit unstable behavior at small scales which are shown to rely on the slope of the shelves.

INTERANNUAL VARIABILITY OF THE DENSE WATER IN THE ADRIATIC SEA FOR THE LAST 40 YEARS.

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The new Adriatic Sea data-set, obtained merging the historical one (Artegiani et al., J.Phy.Ocean. 27(1492-1532)) with data from the MODB (Mediterranean Oceanic Data Base), and from other recent projects such POEM (1985-1993), the European MAST/MTP OTRANTO (1994-1995) and PRISMA (1995-1996), was used to investigate the formation and time-evolution of dense water. The climatological thermohaline fields in the deep layer were obtained, for the first time, by including data from CTD casts that provided measurements down to the bottom. The dense waters formed during winter both in the Northern shelf area and in the Southern Adriatic emerged with greater clarity. The flow patterns of the Northern Adriatic Dense Water, that fills the Middle Adriatic Pit, and the core properties of dense water formed in the South Adriatic Pit by open-ocean deep convection are evidenced. Time series of the mean temperature, salinity and density values have been calculated for the last 40 years, considering the water masses that reside in the main dense water reservoirs. An interannual variability of the Adriatic Deep Water that resides in the Southern Adriatic Pit below the isopycnal surface $\sigma_\theta = 29.2 kg/m^3$ was detected and linked up to climatic changes.

IS DESERT DUST A POSSIBLE ATMOSPHERIC FERTILISER FOR THE MEDITERRANEAN ECOSYSTEM ?

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The role that eolian deposition play in supplying Fe to remote parts of the open ocean and the role that iron limitation plays in controlling primary production in some high nutrient low chlorophyll (HNLC) regions suggests that in these places there may be a direct connection between atmospheric and biological processes. Dust input to the nutrient-limited Mediterranean is one of the greatest in the contemporary ocean (20-50 x 106 tons yr-1) and thus this area is a natural laboratory in which to study the effects of dust deposition on the surface ocean in a setting that is distinct from the HNLC regions. There have been several hypotheses that suggest that this large dust input is responsible for biogeochemical effects yet to date there has been no evidences to elucidating these effects directly.The current mechanisms that have been proposed by which dust affects the surface waters of the Mediterranean can be broken into two kinds: (i) the removal hypothesis states that the scavenging effects of dust remove surface water PO4 and thus reduce surface water productivity; (ii) on the contrary (and not neccessarily mutually exclusively) dust is believed to add PO4 to surface waters during partial dissolution. An alternative enrichment hypothesis suggests that the wet deposition of eolian dust results in enhanced surface water trace element concentrations, thus supplying significant amounts of biologically available reduced Fe.

RECENT REDISTRIBUTION OF HELIUM IN THE EASTERN MEDITERRANEAN

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The distribution of helium in the ocean provides information about pathways of water masses. The results of two cruises of R/V Meteor in 1985 (M5/6) and 1997 (M31/1) are compared with regard to helium data. The component separation procedure to quantify the components of oceanic helium ('terrigenic' ^3He and ^4He released from the ocean floor, 'tritiugenic' ^3He) is applied to the data sets showing that this is a promising method for the data analysis. The helium distributions obtained in this way provide information about the turnover of water masses throughout the Eastern Mediterranean. The redistribution of helium in deep and bottom waters shows that old waters were displaced like it was found in the distributions pf other parameters. A turnover rate is estimated from the changes in the helium distribution.

Identification, Pathways and Mixing of Intermediate Water Masses in the Eastern Mediterranean during October - November 1991.

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The Levantine Intermediate Water (LIW) was historically considered as the dominant intermediate water mass in the Mediterranean, that is mainly formed in Northern Levantine Basin. However, it was reported that slightly denser water of Cretan (South Aegean) origin, the Cretan Intermediate Water (CIW), with similar but distinct (colder and more saline) from LIW characteristics (Theocharis et al. 1993) has been observed outside the Aegean Sea, in the vicinity of the Cretan Arc (Schlitzer et al. 1991). CTD data acquired during autumn 1991 within the POEM program show the presence of intermediate waters of different origin, age and characteristics, occupying the central region of the Eastern Mediterranean. This is possibly related to the dramatic thermohaline change that occured in the region in the last decade. In this work we study the spreading and mixing of the abovementioned masses.

MODELLING THE INTERANNUAL VARIABILITY OF THE ADRIATIC SEA GENERAL CIRCULATION

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The response of the Adriatic Sea general circulation and water mass formation processes to interannually varying forcing conditions has been simulated with the Princeton Ocean Model. An advanced air-sea interaction physics has been implemented in the model. It utilizes the ECMWF Reanalysis 6-hourly atmospheric parameters, the COADS cloud cover data and the model predicted sea surface temperature. The interannual variability of the Po river runoff (northern Adriatic) is also considered. The variability of the Adriatic Sea main circulation features is discussed along with the simulated variability in the dense water formation processes that are compared with available data relative to specific years. In particular, the role of the surface fluxes interannual variability in determining the observed changes of temperature, salinity and density of the central Adriatic deep waters is discussed.

THE TWO REGIMES OF INTERMEDIATE/DEEP FLOW PATTERN BETWEEN THE IONIAN AND ADRIATIC SEA

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The Ionian Sea is the transition basin for the spreading of the Eastern Mediterranean Deep Water from its source, the Southern Adriatic Sea, to the Levantine basin. The Ionian receives the inflow of the Modified Atlantic Water from the Sicily Strait and the inflow of Levantine Intermediate Water. The recent changes in the thermohaline circulation revealed a transition from a system with a single source of deep water in the Adriatic to one with an additional source in the Aegean. The Aegean water was added at great depths displacing upward and westward the less saline old water of Adriatic origin. Consequently a salinity decrease was observed in the northward branch of intermediate water entering into the Adriatic Sea, causing a density decrease of water mass in the Southern Adriatic Pit since 1992. The recent surveys, within the MATER project, show that water masses with core density of 29.19 $kg.m^{-3}$ is exiting now across the Otranto Strait, whereas denser waters (29.24 $kg.m^{-3}$) were documented in the previous regime. The recent ventilated dense waters, which flow out into the Northern Ionian, reside between the 900-2000 m depth. The Ionian abyssal layer is now occupied by warmer and saltier water of Aegean origin (density greater than 29.19 $kg.m^{-3}$). This change suggests the intriguing possibility of two different configurations, between which the deep thermohaline cell of the Eastern Mediterranean has switched from 80's to 90's.

G5 Ocean modelling from altimetry and remote sensing (joint with OA)

Convener: Knudsen, P.
Co-Convener: Le Traon, P.Y.

ASSIMILATION OF TOPEX POSEIDON AND ERS ALTIMETER DATA FROM 1993 TO 1998 IN THE NORTHEAST ATLANTIC

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In the context of the SOPRANE project, we have developped an assimilating model whose aim is to provide real-time operational ocean products including analysis and forecast. This model is derived from the SIMAN model (Blayo et al 1994) and the SOFA optimal interpolation scheme (De Mey 1994). This model covers the Northeast Atlantic from 24° to 54°N and from 35°E to the European/African coast. It features 10 levels on the vertical and a 1/10° horizontal resolution. The assimilation of altimeter data is performed through the succession of 1-week assimilation cycles during which surface altimeter data are assimilated in a model reduced state by optimal interpolation. The full state correction is then computed using the vertical EOF extension scheme first introduced by De Mey and Robinson (1987). A simple - non evolutive - error covariance propagation model is implemented. We have assimilated GDR TOPEX POSEIDON and OPR ERS 1 and ERS 2 altimeter data during the period from 1993 to 1998. The results obtained in the Azores/Canaria domain are discussed in terms of dynamical properties and seasonal variability of the currents. The impact on the assimilation results of the altimeter data processing which is performed prior to the assimilation is also discussed.

TOPEX-POSEIDON DATA ASSIMILATION IN AN OCEANIC GENERAL CIRCULATION MODEL OF THE TROPICAL ATLANTIC

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TOPEX/Poséïdon and ERS-1 altimeter sea level anomalies, eXpendable BathyThermograph temperature profiles, Sea Surface Salinities and Temperatures have been assimilated into a non-linear primitive equation model of the tropical Atlantic ocean during 1993-1994. The results are analyzed by comparison with reference data sets such as the CITHER 1 data set. The emphasis is on thermal, salinity and current structures in the upper layers of the tropical Atlantic. Analysis of transports has also been conducted, especially in the North Equatorial CounterCurrent area.

NORTH ATLANTIC SEA SURFACE VARIABILITY - A COMPARISON BETWEEN ALTIMETRY AND NUMERICAL MODELLING

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More than four years of satellite altimeter data from the Topex/Poseidon mission is used in combination with the EGM96 geoid to derive a series of more than 148 gridded models of the North Atlantic sea surface topography, each one representing a ten-day mean state. This series is used to constitute a long term mean topography and to study in detail the ocean variability in the North Atlantic by means of harmonic analysis and Empirical Orthogonal Functions (EOF).
For the same area, resolution and period of time corresponding topographies were derived by resampling the free surface heights of the Parallel Ocean Climate Model (POCM) of Semtner & Chervin as kindly provided by Dep. of Oceanography, Naval Postgraduate School, Monterey.
The differences between both topographies, the altimetric estimate and the oceanographic model were analyzed with respect to both, the geographical and temporal distribution. It is shown how strong the series are correlated and how well the agreement is for the dominant periodic and aperiodic oscillations.

APPLICATION OF TOPEX/POSEIDON ALTIMETER DATA FOR CEOF AND ALONG-TRACK ANALYSIS IN THE EASTERN ATLANTIC OCEAN AND WESTERN MEDITERRANEAN SEA

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Some global and regional applications to mean dynamic topography, ocean variability and sea-level anomalies are showed using a developped software to process TOPEX/POSEIDON MGDR Altimeter data.
Complex Empirical Orthogonal Functions (CEOF) technique has been applied in sea-level anomalies maps. This technique separates the variance into spatially and temporally uncorrelated modes of variability. Amplitude and phase modes are computed in the San Vicente Cape geographical area (Longitude: 12-18°W, Latitude: 33.5-36.5°N). The first mode represents the 65% of the total variability. The greatest values are associated with the peaks of the variability of the Sea Surface Height, SSH. The second mode represents the 17% of the total variability, indicating that the area is dominated by these two first modes.A collinear, along-track, analysis in an ascending track in the Western Mediterranean is made to show the influence on the SSH caused by ocean tide components. Interpretation of spectral analysis is also discussed.

MESOSCALE VARIABILITY OF CHLOROPHYLL AND SST IN THE CONFLUENCE OF THE BRAZIL AND MALVINAS CURRENTS FROM SATELLITE DATA.

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Subtropical convergence zones, as the confluence of the Brazil and Malvinas currents in the southwestern Atlantic ocean, are key areas for the global carbon cycle and climate since these regions act as large sink of atmospheric CO_2. This is due to the juxtaposition of the effect on pCO_2 of cooling of the southward Brazil current waters with the effect of the photosynthetic utilization of CO_2 in the northward flowing Malvinas current waters. This region is also a highly dynamic, energetic and complex area where remote sensing data can be powerful tools to investigate variability at various spatial and temporal scales. At the moment, there is very little known about the variability of phytoplankton distribution and its correlation with physical processes.
Our purpose here is to analyze the new colour data from the SeaWIFS and POLDER sensors to study mesoscale variability (10-300 km) at a daily frequency. We use those data in conjunction with other satellite data like infra-red sea surface temperature (AVHRR). From first analyses of preliminary colour data, we can observe areas of complex chlorophyll distribution (filaments and eddies) where the two opposite currents meet. We are using analytical techniques for the study of spatial patterns as autocorrelation function and principal component analyses (PCA).

A STUDY OF THE SOUTH-EAST INDIAN OCEAN VARIABILITY FROM ALTIMETRIC, WIND AND XBT DATA.

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We investigate the seasonal and interannual sea level variability in the South-East Indian Ocean from Topex/Poseidon altimetric data. This region is important for climate studies, in relation to the interannual variations of the tropical oceans and atmosphere. The eastern Indian region is directly affected by the strong seasonal monsoons. The Indonesian throughflow between the Pacific and Indian Oceans provides another forcing. As a result, the dynamics of the south-east Indian ocean are unique, with a very large mesoscale variability off western Australia. This eastern boundary is the likely generating region for the westward propagating Rossby waves observed in the subtropical band. These waves affect both the ocean dynamic height and sea surface temperature. In order to explain part of the observed sea surface variability, we use the vorticity equation with the low-frequency quasi-geostrophic assumption to calculate the sea level response to local wind forcing or remote forcing from the eastern boundary. We use ERS-1 scatterometry for the wind forcing; eastern boundary conditions are given by XBT data. First results indicate that significant correlation exists between the calculated variability and sea level variability observed by T/P. A comparison with numerical model output will also be discussed.

MODELING WIND-FORCED SEASONAL-TO-INTERANNUAL VARIABILITY OF SEA SURFACE HEIGHT IN THE NORTH PACIFIC

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The TOPEX/POSEIDON sea surface height data show a temporally and spatially varying response to wind-forcing in the North Pacific that appears to be a combination of freely propagating and forced Rossby waves. An isopycnal ocean model is used to investigate the role of the wind, stratification and topography in governing SSH fluctuations. The model is forced by seasonally varying winds; both with and without bottom topography. The spatial structure of the wave response is sensitive to the stratification as it influences the phase speed of the first-mode baroclinic Rossby waves. The topography has little influence on the wind-response south of 30N, where the first baroclinic mode appears to dominate SSH variations in the observations. North of 30N the barotropic mode is important, hence the topgraphy influences the solution. As in the observations, the model shows a seasonal modulation in SSH variability at mid-latitudes but not in the tropics, suggesting that local winds are important for forcing the wave response. In the model and the observations the SSH variability is larger in the western Pacific at mid-latitudes than in the eastern Pacific.

THE 1996 SEA SURFACE HEIGHT ANOMALY OF THE NORTH ATLANTIC SUBPOLAR GYRE

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A sea surface height time series from the TOPEX/POSEIDON altimeter data as provided by AVISO's corrected sea surface heights (CORSSH), was taken to investigate sea level anomalies in the North Atlantic. The period from 1992-1996 was used to perform a long term Mean Sea Level (MSL). Comparing this MSL with annual and seasonal mean fields an anomalous sea surface height feature could be significantly identified for the year 1996. This anomaly becomes in particular clear, when periodic variations of the sea surface were identified and removed. The observed anomaly coincides with a drastic decrease of the NAO in 1996. Variations in sea surface temperature data (taken from AVHRR) and sea level pressure data (from NCAR/NCEP) were analysed by similar methods in order to investigate correlations between these data sets and to study the impact of the inverted barometer correction to the CORSSH.

SATELLITE DATA ASSIMILATION IN THE OCCAM GLOBAL OCEAN MODEL

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As part of the european AGORA programme we have been assimilating TOPEX/POSEIDON altimeter data into the Southampton Oceanography Centre's high resolution ($\frac{1}{4}{}^\circ \times \frac{1}{4}{}^\circ$, 36 level) global ocean model (OCCAM). The assimilation method used is that of Cooper and Haines (1996), a dynamically based method which conserves water properties on isopycnal surfaces.
Results of a one-year, 1993, run of this model, driven by ECMWF 6-hourly winds and assimilating 10-day mapped TOPEX/POSEIDON data are presented. These results are compared firstly with results from the OCCAM model without altimeter assimilation. This way we can assess the impact of the assimilation both on the mesoscale processes and on the large-scale exchanges and transports. Secondly, the simulation is compared with independent datasets, particularly hydrographic data. These comparisons concentrate on three regions, Tropical Pacific, North Atlantic and the Southern Ocean.
Results of a method to improve the model mean sea level, particularly in the Gulf Stream and Kurushio separation regions, will also be shown.

EVALUATING SOUTHERN OCEAN RESPONSE TO WIND FORCING

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Winds over the Southern Ocean are among the strongest in the world, but the magnitude and variability of these winds is not well known. Because of the paucity of in situ measurements, Southern Ocean wind fields derived from numerical models have been notoriously suspect. New satellite wind measurements provide a more accurate means to estimate changes in wind forcing of the Antarctic Circumpolar Current. In this study, temporal variations in winds derived from the ERS scatterometers, from SSMI, and from the ECMWF forecast model are correlated with variability in Southern Ocean pressure and transport derived from the UK bottom pressure recorders in Drake Passage. Winds and bottom pressure measurements both show substantial variability on all resolved time scales. To extend the spatial coverage of the study, the winds are also compared with surface transport estimates reconstructed from Topex/Poseidon altimeter measurements. Finally the response of the ocean to wind fluctuations in data is compared with analogous quantities from ocean general circulation models.

THIRD-ORDER STATISTICAL CHARACTERISTICS OF WAVE FORMS IN RADAR REMOTE SENSING OF SEA SURFACE

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The problem of reconstruction of ripple energy distribution over large areas of sea surface from radar measurements is considered. The importance of the problem lies in the fact that the small-scale surface oscillations are sensible to weak surface flows, which, in turn, may reveal the nature of large-scale processes taking place in the sea depth.
The investigation of statistical properties of backscattering was performed by numerical simulation. An ensemble of wavy surfaces simulating sea-way process gives rise to an ensemble of corresponding backscattering amplitudes, and the statistical characteristics of the two ensembles are considered. It is found that the sea-way spectral energy distribution, taken alone, does not provide enough essential characteristics to describe statistical properties of backscattering. New quantitative characteristics of skewness of wave peaks, ripple localization etc. are based on bispectrum — third order statistics of the surface elevation.
The results show that it is the small-scale wave form peculiarities that may account for some fine backscattering properties, e.g. upwind-downwind asymmetry. Thus the large-scale waves may be treated as independent, whereas the nonlinear consideration for small scales is necessary. The possible improvement of existing statistical model of sea surface is discussed.

ALTIMETER-BASED REFINEMENT OF TURBULENT DIFFUSION COEFFICIENTS

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One of major factors responsible for ocean transport of heat, salt, and bio-geochemical quantities is the horizontal turbulent diffusion caused by "sub-grid" variations of ocean current velocity. Using a recently developed technique of altimeter data analysis, statistical characteristics of the slow, i.e. vortical component of ocean dynamics can be derived from the sea surface height (SSH) field. Vortical motions are responsible for horizontal turbulent diffusion on large scales, and Richardson-type relationships allow expressing the diffusion coefficient in terms of energy and enstrophy spectral fluxes in 2D turbulent cascades. We demonstrate how these fluxes can be estimated and the coefficients of horizontal turbulent diffusion refined based on appropriate statistical characteristics of SSH variations.

VELOCITY AND TRANSPORT OF THE LABRADOR CURRENT DETERMINED FROM ALTIMETRIC AND HYDROGRAPHIC DATA

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TOPEX/POSEIDON altimeter data from 1992 to 1996, in conjunction with hydrographic and meteorological data, are analyzed to examine currents and transports in the Labrador Sea, with an emphasis on seasonal variability of the Labrador Current. Based on the linearized momentum equations, vertically integrated velocities and transports on selected sections across the Labrador Sea are computed. The seasonal range of the Labrador Current transport from the shelf break to the 2500-m isobath varies from 17 Sv at the Nain section, to 6.5 Sv at the Hamilton Bank section and 5 Sv at the northern Newfoundland section with maximum in winter and fall and minimum in spring. Horizontal density gradient and sea surface slope have comparable contributions to the seasonal variability. In comparison, the contribution of the Ekman transport forced by local wind stress is much smaller. Except for the Nain section, the seasonal variability in the lower continental slope is weaker than that over the shelf break and upper slope. An exploratory study of the absolute mean transport of the Labrador Sea is carried out using available geoid data. A mean transport of 23 Sv in the Labrador Current (shoreward of the 2500-m isobath) and a basin-scale transport of 50 Sv in the Labrador Sea are obtained, consistent with Reynald et al.'s (1995) results.

SYNTHETIC GEOID FOR MESOSCALE STUDIES OF THE AZORES CURRENT

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The SEMAPHORE-93 mesoscale air/sea experiment took place in the Azores front/current domain from June to December 93. About 40 ARGOS-tracked surface drifters, drogued at 150 m depth were deployed and three hydrological arrays were performed. Moreover, ERS-1 and TOPEX/POSEIDON (T/P) were flying at that time. The altimetric data were processed using the collinear passes method, as part of the CANIGO project. They are in excellent agreement with in-situ measurements. The comparisons with dynamic height fields objectively mapped from XBT/CTD casts show 4-5 cm rms differences. Also, comparisons with drifter velocities close to the satellite ground tracks exhibit 7-9 cm/s rms differences. But because of the lack of a precise geoid the total ocean circulation cannot be inferred from satellite altimetry. Thus, SEMAPHORE data are combined by multivariate objective analysis to provide maps of the surface circulation. Then, over 6 months, the differences between altimetric and in-situ maps are used to build a synthetic geoid in the area. Based on this reference field, the Azores current circulation is monitored from 1992 to 1997 using ERS-1, ERS-2 and T/P data.

RESIDUAL ERRORS IN DUAL-SATELLITE CROSSOVER ALTIMETRY DATA: AN INDEPENDENT CHECK

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Typical lifetime of an altimetry mission is five years. Dual-Satellite Crossovers (DSCs) have been recognize as a useful tool to interconnect two or more altimetry missions to provide oceanographers by long-term series in a unified system with the same "geodetic constants" to avoid any misinterpretation of the data. One obstacle to create such series comes from different realization of geocenter of various altimetry orbits. It was revealed by means of the DSCs, using the JGM-2 and JGM-3-based orbits (with up-to-date environmental, empirical and other altimetry corrections) that there is statistically significant geocenter offset between Geosat and T/P. We can provide oceanographers by corrected DSCs of Geosat - T/P for 1986-1996. To increase confidence in our results, we performed various tests, including use of specific *combinations* of the DSCs. The formulae and method have been worked out in Ondřejov and tested with data from Silver Spring. Recently, GFZ has been asked for a check. The DSC long-term averaged residuals and their combinations were computed independently in GFZ, Oberpfaffenhofen and compared to results from NOAA, Silver Spring. The DSC residuals are a composite of non-perfect media. 1 cpr empirical, tidal and other corrections. These effects are estimated by a new diagnostic method (developed in Ondřejov) based on the DSC combinations.

An integrated system for handling, analysis and visualization of ocean data

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"Busstop", an integrated system for handling, analysis and visualization of ocean data, is presented. Busstop integrates functionality typically found in Geographical Information Systems (GIS), image processing systems and data base management systems, and provides a smooth interface to user written programs. The traditional spatial GIS functionality has been extended with transparent support for temporal data as well, enabling the GIS functionality to work even as a tool for analysis of dynamic phenomena. The Busstop data model integrates point data and grid data in a more general model, which is useful for combining satellite altimetry with ancillary data on gridded form. The visualization subsystem, called Reveal, provides functionality for static and animated visualization of gridded data, and combined views of gridded and point data. Additional analytical and data handling functionality is currently being developed. Proof-of-concept studies, carried out using the PC based prototype version of Busstop, has included studies involving combination of satellite altimetry with atmospheric model data, sea surface temperature data, gravimetry and airborne altimetry. Additionally, the system has been used for explorative visualization in case studies involving SAR scenes, and output from an ocean tide model. Busstop has shown very useful as an integrated and integrative platform for multidisciplinary ocean studies.

HIGH RESOLUTION MEAN SEA SURFAES FROM MULTI MISSION SATELLITE ALTIMETRY

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Satellite altimetry from the GEOSAT and the ERS-1 geodetic missions provide altimeter data with a very dense coverage. Hence, the height of the sea surface may be recovered very detailed. Satellite altimetry from the 35 days repeat cycle mission of the ERS satellites and, especially, from the 10 days repeat cycle TOPEX/POSEIDON satellite mission provide accurate mean sea surface heights along the ground tracks of those missions. In this study averaged sea surface heights of the repeat missions were used to construct an accurate mean sea surface. To enhance the resolution of the mean sea surface the altimetry from the geodetic missions was utilized. Marine geoid heights derived from the altimetric gravity was used for this task. The advantage of such a procedure is that inconsistences along the edges of the small cells may be avoided. The TOPEX/POSEIDON mean sea surface heights relative to the mean heights over 50 km are fitted by 2 cm and the slopes fit within a few mm per km.

GENERAL INVERSE OF A SHELF TIDE MODEL: APPLICATION TO THE M_2 TIDE IN THE BARENTS SEA

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When the general inversion is used to assimilate data into a model of a closed basin, a solution minimizes a weighted sum of square misfits in dynamic equations, the data, and a boundary condition at the coast. However, if the problem is solved for a shelf region, there is usually lack of quantitative information about the tides at an open boundary. Thus, to make the problem well-posed, we augment the cost functional with a regularizing term which penalizes large surface elevation at the open boundary. Then the science lies in the specification of the relative weights for different terms in the functional. Following our procedure, optimal weights for the data and the coastal boundary condition misfits would give a maximum to the sum of those terms (which reflect quantitative information). The weight for the regularizer (qualitative information) would be taken the biggest at which the solution is still not sensitive to its choice. The technique was used with a finite element model for the M_2 tide in the Barents Sea where in-situ and satellite altimetry data were both available. Although no boundary condition was assigned at the open boundary (for instance, taken from a global model), the rms deviation of the solution from surface elevation data not assimilated into the model was 4.4 cm which is much better then results obtained with other models.

LARGE SCALE SEASONAL VARIATIONS OF ATLANTIC OCEAN BY COMBINING ALTIMETRIC AND HYDROGRAPHIC DATA IN AN INVERSE MODEL.

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An attempt is made to observe the response of Atlantic ocean from seasonal atmospheric forcing using an non-linear inverse model (Mercier, 1992). 3 years of Topex-Poseidon GDR (T/P, cycles 11 to 121), wind stress (ECWMF), and net heat flux (ECWMF, COADS) were combined with a new climatology built from NODC data (Reynaud, 1995). Inverse formalism allow us to ajust the velocities at the reference level, and the density field. Particular effort is made on heat conservation constraint where evolution terms (deduced from hydrograhpy, but also from altimetry) were added. A posteriori solutions give a good picture of the Atlantic general circulation between 20°S and 60°N. Heat conservation constraint has a strong impact in depth, implying seasonal variability of DWBC. Then, intensifcation of meridionnal overturning is find to bring heat from equator to northern latitudes during winter. Altimetric constraint is not useful when absolute dynamic topography deduced from T/P and EGM96 geoid is employed due to large errors in the geoid. Nevertheless, results with T/P sea level anomaly using in the model as a constraint on the anomaly of the surface dynamic topography are satisfying. Results, first demontrate consistency between seasonal anomaly of hydrography and altimetry data, and secondly, show that altimetric information is able to constrain surface circulation, especialy in tropics.

The Diagnostic Analysis of Baroclinic Ocean Dynamics by Satellite Altimetry Data.

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The diagnostic analysis of ocean dynamics by satellite altimetry data may give complete hydrodynamical picture on that time moment, when appropriate measurements were made. The first valuation of baroclinic ocean dynamic structure can become definition barotropic (average on depth) mode of speed field, designed through integrated stream function on the basis of satellite information. As an initial system of offered model equations are considered equations of ocean dynamics in quasigeostophic approximation. The boundary condition on surface for vertical mode of speed fields is replaced by "firm cover" condition, and a condition of sliding without friction is at the bottom taken. For processing of satellite altimetry data, when the density field on whole ocean height is not known, is offered to search integrated stream function as anomalies from mean (mean season) significance. By virtue of it is possible to make the assumption that the changes of baroclinic layer thickness (in which are concentrated main density changes, and the which thickness is small in comparison with depth of ocean) are insignificant. In the first approach it is possible to consider, that the density anomaly concerning mean significance on a linearly change by vertical from surface significance to zero on the baroclinic layer bottom border. The account of dynamic topography on satellite altimetry data is carried conducted on mean sea surface field and geoid height. The model verification was conducted on independent data: satellite altimetry (ERM mission GEOSAT) and hydrological data (experiment NEWFAEXP-88 the program SECTIONS) for polygon Newfoundland Ocean Energy Active Zone in march 1988. In the first numerical experiment of dynamic topography anomaly was designed by hydrological data and simulated by self of satellite altimetry processing results. In the second initial information was considered directly by remote data from GEOSAT board. The mean fields of dynamic topography and integrated stream function were determined by known data file LEVITUS. The results analysis has shown, that integrated stream function fields and barotropic speed mode, received in result of imitation experiment, will be well agreed results of diagnostic accounts by density field. Thus, the offered model may with sufficient accuracy to define barotropic speed mode of baroclinic ocean by satellite altimetry data.

SEASONAL TIDE VARIATIONS AND SHALLOW WATER TIDES FROM TIDE GAUGES AND ALTIMETRY

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TOPEX/Poseidon altimetry has during recent years greatly improved our knowledge of ocean tides. A remaining problem in ocean modelling, however, arises from the contributions of meteorological forcing, nonlinear coupling with storm surges and ocean circulation, and internal tides. Here we investigate the temporal variation of tidal solutions at tide gauges and as observed by altimetry, and try to identify its possible relation to the above effects.

nother challenge is to improve our models near coastal boundaries, where many existing T/P-based ocean tide models are inadequate due to the coarse spatial sampling and the additional presence of significant third- and fourth-diurnal constituents.

In a initial investigation for the North Sea, it was recently shown that T/P has the potential of improving our knowledge of even these near-boundary tides, such as M4, which may be as large as 20 cm. In this presentation we will extend our efforts in this area.

Additionally, we look at the potential of adding data from the ERS mission to further improve our altimetry-based results.

BIO-OPTICAL EMPIRICAL MODELS OF THE WATERS ADJACENT TO TAIWAN

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Optical properties of seawater in the waters adjacent to Taiwan area were measured by underwater spectroradiometer during four cruises from December 1996 to March 1997. Water samples were collected at the same time and analyzed for chlorophyll-a concentrations. Parts of the existing bio-optical models from SeaWiFS Bio-Optical Algorithm Mini-Workshop (SeaBAM) shown in Table 1 are used in this study.

POLDER ON ADEOS: A NEW OCEAN COLOR DATASET TO COMBINE WITH ALTIMETRY

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With OCTS and POLDER the ADEOS mission is the first of a series of upcoming missions providing global Ocean Color datasets (SeaWIFS, EOS/MODIS, ADEOS2 with GLI & POLDER2). The POLDER (POLarisation and Directionality of the Earth's Reflectances) sensor is an imaging radiometer-polarimeter designed to measure the solar visible and near infrared radiation reflected by the Earth/atmosphere system. In addition to the classical measurements and mapping capabilities of a narrowband multispectral imaging radiometer, the POLDER concept has original polarization and directional capabilities which open new perspectives for sensor calibration, glitter rejection, atmospheric corrections and inversion of pigment concentration. Data have been acquired since October 30, 1996 till ADEOS loss on June 30, 1997. The calibration phase has been completed in May 97. The geophysical validation phase is ongoing, based on a dual strategy combining statistical approach and enhancement of in situ (atmospheric and oceanic) measurements networks.
Global results of POLDER marine parameters products and comparison with historical CZCS data will be presented. Potential applications in global biogeochemical studies include : i) the provision of synoptic fields of chlorophyll concentration to compare against the field derived from coupled, ocean-ecosystem models, -a comparison with a 3D modelling study in the North Atlantic will be shown- or to use for assimilating and/or initializing such models, ii) a basis for the computation of regional and basin scale estimates of primary production and iii) a generic vehicle for the extrapolation to large horizontal scale of small numbers of in situ discrete observations of various ecophysiological rates and pools. Correlation analysis with altimetry data will be illustrated in two subtropical gyres frontal zones, namely the Brazilian-Falklands Confluence zone and South African Convergence zone.

A variational assimilation model for the barotropic tides in a global ocean: principles and application to the long period tides

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The CEFMO model (Finite Elements Code for the Oceanic Tides) has been developed to produce high resolution solutions over the world ocean. In addition, an assimilation code has been developed to improve the solution accuracy by assimilating in situ and altimetric observations. It is based on a general inverse approach using the representers technique. One main characteristic of our assimilation approach is to formalize it as a continuous (i.e. not discretized) problem, leading to a pair of linear systems to be solved (adjoint and direct). Similarly to the hydrodynamic problem, they are treated under their variational formulation. First designed to solve the tidal problem on ocean basins, the hydrodynamic and assimilation models have been upgraded to produce global solutions where the inter-basin constraints are totally removed. A preliminary set of solutions for the main long period tides have been computed and validated. Our solutions show a very complex spatial distribution due to large wavelengths combined with small structures coming from the trapping of the tidal waves by the topography. The set of reliable observations, to be used in the assimilation, shows a poor density compared to the richness of the modelled spatial scales. Nevertheless, this application is an ideal test case to evaluate the robustness and the effectiveness of our modelling and assimilation approach.

LONG TERM MONITORING OF THE OCEANIC PRIMARY PRODUCTION SOUTH OF SOUTH AFRICA : USE OF THE REMOTELY SENSED DATA

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In order to better constrain the carbon fluxes in the southern ocean, the role of mesoscale eddies in biological production has to be elucidated in the large sink areas of the subtropical convergence zones. Causes of the variability of the phytoplankton distribution in relation to the forcing induced by the physical environment are studied in the eastern boundary current system of the South Atlantic ocean. The area of interest is the Agulhas current and its retroflection along with the upwelling area of the Benguela current. Remotely sensed data from POLDER and SeaWiFS for ocean colour are used in conjunction with other remote sensing data (SST, dynamical heights, surface winds) in the Agulhas/Benguela region. Standard statistical data analyses such as PCA and wavelets are applied to determine the nature of the temporal and spatial variability. As expected, phytoplankton variability shows correlation with the SST variability at the mesoscale. Correlation of ocean colour with altimeter data helps us reveal the underlying dynamical nature of the region. In the subtropical convergence (STC), a strong thermal gradient and an extended frontal area, created both by meandering Rossby wave of the ARC and eddies spawned at the STC lead to an increase of primary production. This enhancement occurs on a large oceanic area and then is of great importance in carbon fluxes estimation.

INTERANNUAL VARIABILITY IN THE EASTERN INDIAN OCEAN

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Interannual variability in the eastern Indian Ocean is investigated with the aid of Topex/Poseidon data, Reynolds SST data and a 10-year, monthly repeated XBT transect at the eastern boundary. The interannual variability in this region is influenced by local and remote wind forcing, and by the remote ocean forcing via the Indonesian Throughflow which allows interannual variations in the western Pacific to directly influence the eastern Indian Ocean. In addition, the south-eastern boundary includes the source of the annual westward propagating signal at 10°S and significant semi-annual Rossby wave activity between 20-35°S, which contribute to carrying the interannual variations from the eastern boundary into the ocean interior. The interannual signature in the mid-latitude propagating anomalies is apparent in T/P sea level anomalies (SLAs) and SST anomalies. Large-scale warm SST anomalies lasting several months also occur in the ocean interior, which coincide with the arrival of downwelling Rossby waves with positive SLAs, and possibly induce the observed upwelling-favourable winds which occur at the end of the warm SST anomaly.

TRACKING EDDIES IN THE SUBTROPICAL NORTH-WESTERN ATLANTIC OCEAN

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Anticyclonic eddies generated in the North Brazil Current (NBC) retroflection area are traced along the coast of North Brazil into the Caribbean Sea via altimetric SSH measurements by TOPEX/POSEIDON. At least 16 to 20 eddies can be seen to form in the NBC area during the period from October 1992 to June 1997, 12 of which can be followed into the Caribbean Sea, where they appear about one year after their generation. It takes them about 350 to 370 days to propagate from their formation area at about 5°N - 8°N and 315°E - 320°E into the Caribbean. Time scales of about 80 to 100 days, characteristic for the Caribbean, can already been found in the region of eddy formation. The observed eddy sizes range from 200 to 600 km. Their average amplitude is found to be about 15 cm, and their average propagation speed is about 14 cm/s. Thus, the connection of a continuous eddy path from the NBC area into the Caribbean, recently indicated by model calculations with a high-resolution (1/6°) ocean circulation model, has been shown to appear in the TOPEX/POSEIDON sea surface height anomalies.

APPLICATIONS OF HIGH ACCURACY ALTIMETRIC HEIGHT MEASUREMENTS IN ICE COVERED SEAS TO STUDIES OF THE POLAR OCEANS, AND COMPARISONS WITH MODELS

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The use of altimeter data in the polar regions has previously been restricted by the presence of permanent and seasonal ice cover. Changes in the radar echo shape received by the altimeter over sea ice, as compared with the open ocean, cause problems in the on-board estimates of surface height, resulting in a very noisy height signal. The majority of noise on the signal can be reduced by retracking the full waveform data set (WAP), but other factors have previously limited the noise reduction, most notably pulse blurring. Software simulation of the tracking system has led to the development of new ground processing algorithms, which further reduce the short wavelength (< 20km) noise, from 30-50cm, down to 5-10cm. This provides for the first time the capability for accurate mean sea surface generation and investigations into tidal and oceanographic signals in ice covered seas. The initial estimate of the rms variability of crossovers in the Arctic is 14-20cm, compared with a global average of 6-8cm. Sea surface anomalies are calculated over the Arctic Ocean and their potential in improving our understanding of tides and ocean circulation is explored through comparisons with existing models.

REGIONAL ANALYSIS OF THE INVERTED BAROMETER EFFECT OVER THE GLOBAL OCEAN

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Crossover sea level differences from TOPEX/Poseidon are regressed against atmospheric surface pressure, and the resulting latitude/longitude map of the regression coefficient is examined for deviations from the value of -1 cm/mbar expected for an inverted barometer (IB) signal. Such deviations can be caused by incidental correlations between measured atmospheric pressure and data errors or correlations between atmospheric pressure and dynamic sea level (i.e., sea level adjusted for an IB signal). Significant departures from the constant IB value are found in most regions, from the tropics to high latitudes. An ocean model is used to help interpret the observed IB departures and their spatial patterns in terms of the spatial characteristics of the forcing, the differences in regional dynamics and oceanic response to forcing, and the effects of wind-driven signals. Influence of high frequency signals, not well sampled by the altimeter, is discussed. The general validity of the IB approximation is assessed as a function of time scale and region.

SPACE-TIME VARIABILITY OF THE BLACK SEA GEOSTROPHIC CIRCULATION AS IT SEAN FROM SATELLITE ALTIMETRY.

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The Black Sea is a semi-enclosed sea with a strong seasonal variability of the sea level due to seasonal cycles of river runoffs, precipitation and evaporation. Both the ERS-1 and the TOPEX-POSEIDON altimetry obviously present the strong seasonal signal with the amplitude up to 25 cm that need to remove before the analysis of the surface geostrophic circulation. The altimeter data averaged along each track shows that the response of the offshore sea level to the water exchange is spatially uniform. It results from the barotropic nature of the response as well as from the fact that the size of the Black Sea is significantly less than the barotropic Rossby radius. The latter idea serves a basis of the proposed method of retrieving the anomaly of the Black Sea dynamical level, namely, the level, which reflects the surface geostrophic circulation. To obtain the outcome product the climatic sea level from the archive hydrology is added to the anomaly of the dynamical sea level from altimetry. The reconstructed dynamical sea level shows good correlation with the sea level obtained from the simultaneous CoMSBlack hydrology. The objectively mapped dynamical sea level is used to analyze a seasonal variability of the Black Sea circulation. The satellite altimetry manifests a well-known cyclonic Rim Current belting the Black Sea. The Rim Current has its maximum intensity in the winter-spring period. There is a break in the Rim Current beginning from the earlier summer. Simultaneously the mesoscale eddies occupy the basin. By the end of the fall the eddy activity weakens and the Rim Current recovers. Then the cycle repeats. Wintertime intensification of the Rim Current corresponds to the seasonal intensification of the atmospheric cyclogenesis over the Black Sea. The time-longitude plots of the sea level anomaly demonstrate the westward phase propagation. Thus the seasonal variability of the Black Sea circulation results from the seasonal variability of atmospheric forcing and the reflection of Rossby waves from the eastern coast of the Black Sea. The spectral analysis shows that mesoscale contains a substantial part of the total energy besides the seasonal cycle. The time spectrum clearly shows two periods of about 130 and 60 days. The eddy activity is the most prominent in the Rim Current vicinity. There are additional areas of the enhanced mesoscale variability in the westernmost part of the Black Sea, near the Bosphorus Strait, and near the bottom slope in the central part of the eastern Black Sea.

MONITORING THE 1997/1998 EL NIÑO BY ERS-2

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The recent El Niño of 1997/1998 is one of the strongest in this century. With the radar altimeter and Along-Track Scanning Radiometer (ATSR) of ERS-2 this event was monitored in high detail. From the OPR-1 altimeter data, enhanced with Delft precise orbits, weekly "images" of the sea level anomalies are generated, each with an effective temporal resolution of 16 days (one subcycle of ERS-2) and with a fine spatial resolution of about 1.5°. Adding to this the ATSR sea surface temperatures, which are unfortunately hampered by cloud cover, we have an excellent set of data to study the evolution of the ocean dynamics in the Equatorial Pacific related to the El Niño Southern Oscillation (ENSO) from May 1995 onward. Animations clearly show the development of the latest El Niño. Especially the sudden Kelvin wave at its onset is clearly recognised as well as the fact that the event actually hits the American coast twice, in July and October 1997.
The altimeter data have been assimilated in a wind-driven shallow-water ocean model using variational and ensemble Kalman techniques. In this way we were able to bring the model sea surface elevations closer to the observations; the rms difference dropped from about 8 to 4 cm. Definitely, the incorporation of altimeter data improved our analysis and shows the potential of these data in ENSO dynamics research.

EOF- AND WAVELET ANALYSIS OF THE SEA SURFACE VARIABILITY

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A series of global gridded sea surface height models has been generated from Topex/Poseidon altimeter data, covering a period of at least four years. Height anomalies, performed relative to a four year mean sea level, are used to study the sea surface variability using the method of empirical orthogonal functions (EOF) and principle components as well as wavelet analysis.
The space-time distributed height anomalies are separated into temporal parts, represented by the principal components, and spatial parts, described by the empirical orthogonal functions. The latter are computed by a singular value decomposition of the matrix of the height anomalies.
The principal components are investigated by wavelet transform in order to determine both the dominant periodic and the significiant aperiodic oscillations of the sea surface. The wavelet method is an excellent tool for analysing signals with time dependent amplitudes and/or frequencies. Local signal variations are detected in an adaptive time-frequency window. The current analysis is based upon the Morlet wavelet, often used in geodetic applications.
The spatial and the temporal distribution of the first few modes are shown together with the results of the wavelet transform of the principal components. This illustrates how the annual variability as well as phenomena like El Nino are represented.

MECHANICAL ENERGY FLUX TO THE SURFACE GEOSTROPHIC FLOW USING TOPEX/POSEIDON DATA

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The rate of mechanical energy transfer from the atmospheric winds to the surface geostrophic velocity is estimated for the world ocean. The surface geostrophic velocity is calculated from the 4 year mean dynamic topography and the 10 day anomaly fields obtained from the TOPEX/POSEIDON altimetry measurements. The wind stress is obtained from the NCAR/NCEP Reanalysis. An uncertainty estimate of the integrated energy transfer rate is more computationally demanding and therefore focused on just the North Pacific basin. The uncertainty is based on the geoid slope error estimates obtained from the JGM-3 geoid model coefficient covariance matrix. Despite the low signal to noise ratio, a meaningful signal can be extracted since the energy transfer calculation involves a projection of the estimated geostrophic current onto the wind stress field. The latter is more strongly correlated with the surface current than the geoid slope error.

ASSIMILATION OF TOPEX/POSEIDON DATA INTO A SEASONAL FORECAST SYSTEM

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By assimilating T/P altimeter data into the oceanic component of a coupled ocean-atmosphere model we want to improve the seasonal forecast system at ECMWF. As a first step we compare gridded T/P data to results from the present forecast system in which XBT and TAO temperature observations are assimilated into the ocean model via OI and SST is relaxed to Levitus. The mean value of the sea level for the years from 1993 to 1995 is subtracted from the model results and T/P anomalies are interpolated to the model grid. In general, both the mean annual cycle and the interannual variations agree quite well between observations and model results, including the onset and time-evolution of equatorial Kelvin waves and off-equatorial Rossby waves. There are spatial shifts of the anomaly-patterns however, and the T/P data show enhanced mesoscale activity. Amplitudes of the sea level are generally somewhat larger in the observations.
Thus, T/P data have the potential to improve oceanic initial conditions. Using altimeter data is not easy however. As a first attempt, T/P data are assimilated into the ocean model by locally adjusting the vertical density profiles as suggested by Cooper and Haynes (1996). Later efforts will include the combined assimilation of TAO, XBT and T/P data. The relative importance of the different observation systems will be assesed.

ASSIMILATION OF ALTIMETRIC DATA IN AN OCEAN MODEL FOR FISHERIES STUDIES IN UPWELLING AREAS

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The coastal ocean upwelling phenomenon is an important processes studied in oceanography. Many studies based directly on satellite observations were carried out to locate and follow this phenomenon on the ocean surface. Advanced data assimilation methods are essential to infer its subsurface dynamics in deep and shallow ocean from satellite data. With the tidal mixing, the coastal ocean upwelling constitutes the major process for nutrient regeneration in the surface layer. The surface Ekman layer transport produced by the phenomenon, and related currents are an important factor for larvae and small pelagic life. Studies and investigations using satellite and fisheries data and some assumptions on the current behaviour try to identify the physical forces that control the growth of small pelagic fish populations. Up to now (to our knowledge), the dynamics resulting from the assimilation of satellite observations have not been used for studies in this discipline.
A project is undergoing at the JRC SAI/ME unit to assimilate altimetric data in a primitive equation model using a four-dimensional variational assimilation scheme, in order to obtain such a description of the dynamics in upwelling areas. More details of the project and its current state of development will be presented during this session of the EGS General Assembly.

THE BLACK SEA VARIABILITY RESULTED FROM THE WATER BUDGET.

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Seasonal variability of river runoff, evaporation, precipitation and water flow through Bosporus and Kerch straits induces changes of the Black Sea level with amplitude up to 35cm. Simple two-layer model analysis shows that the response of the closed basin to the boundary water fluxes is barotropic mainly. Moreover, it is spatially uniform in the deep part of the Black Sea since the size of the basin is much smaller than the barotropic Rossby radius. Satellite altimetery data of TOPEX/POSEIDON and ERS-1 missions provides unique possibility to verify the theoretical results. Averaged data along each track, crossing the Black Sea are used. There is good correspondence of different time series obtained after the averaging of the open sea level data. These data are also in good agreement with river runoff, recalculated to the mean Black Sea level variability due to the continuity equation. The behavior of the sea level in the shallow coastal zone is more complicate. There is the phase shift between coastal sea level observations and satellite altimetery data for the open sea. Coastal sea level observations itself demonstrates also the phase shift between data sets obtained in different points along the Black Sea coast. Coastal trapped and shelf waves are the most feasible causes of the observed sea level structure.

SURFACE MEDDIES TRACKING USING SPATIAL TECHNIQUES

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The analysis of ocean water masses using traditional oceanographic techniques, including RAFOS, has allowed to track the upwelling of Mediterranean water forming mesoscale eddies, with a different thermohaline composition of its surrounding Atlantic masses, in the Iberian Atlantic west of the Portugal coast. The dynamic of the region is quite complex and is of particular interest to use data assimilation that combines classical and spatial techniques. To detect MEDDIES with satellite altimetry we have defined a rectangle between longitudes 340° and 353° and latitudes 36° to 43°N, where MEDDIES where detected by lagrangian methods, according with information received from the Portuguese group IOCEANO. With preceding information we have compared, on this geographic area, the behaviour of the different altimeters, tracking along its paths the dynamic signal time series. A comparison was also made between the average behaviour of the dynamic signal over windows with a surface extension of the size of the MEDDIES (0.5°X0.5°) and a dynamic sea surface reference obtained averaging the time series over larger windows of 3°X3°. Our result shows the track of a possible MEDDIE crossing the area from 38°N, 12°E in 26 July 1994 to 37°N, 13.7°E in 26 August 1994. The possible MEDDIE was simultaneously tracked by two RAFOS and detected as a different signature surface in an ERS-1 SAR image.

THE POTENTIAL FOR USING OCEAN GENERATED ELECTROMAGNETIC FIELDS TO REMOTELY SENSE OCEAN VARIABILITY

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The flow of the electrically conducting ocean through the Earth's main magnetic field generates secondary electromagnetic fields. For some time electric field measurements have been made in the ocean to determine the ocean flow. D. Winch and K. Runcorn have speculated recently that magnetic field satellite surveys might be used to monitor the ocean generated electromagnetic fields, and that these signals might be inverted to gain information about variations in ocean circulation. We calculate global three-dimensional electromagnetic fields generated using ocean data from the German OPYC model and give an overview of the form and magnitudes of the ocean generated electromagnetic fields both in and outside of the ocean. The ocean-generated magnetic fields are typically less than 10 nanoteslas outside of the ocean (but can reach a couple hundred nT inside the ocean) and although small are above the detectability level of ground observatories and some of the previous satellite measurements. We discuss these results and describe both the potential benefits and difficulties in extracting and inverting the ocean signals from the geomagnetic records. Discussion of this topic is timely since the potential use of satellite magnetic data in ocean and climate studies could be made more feasible with coordinated efforts in future satellite missions such as CHAMP.

Radar investigations of the deep-ocean internal solitons in the North-Western Pacific

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A detailed analysis of sea surface Ku-radar images collected in IKI RAN during regular many years experiments (1979-1991) from aircraft has showed that in the North-Western Pacific near Kamchatka there were the regions of regular manifestations of deep ocean internal waves. Some of the soliton-like trains of internal waves seemed to propagate from the open ocean to shelf. The direction of propagation of the trains was estimated using some specific features in the trains' surface manifestation. The simultaneous contact measurements of hydrological and oceanographic parameters from research vessel have confirmed the availability of internal waves in the testing area. The ray calculations have confirmed that there are some locations at the continental slope where the slope inclination is critical for the semidiurnal internal tide. The internal tides generated in these locations propagate along the wave characteristics (rays) and may evolve in the upper ocean in trains of the solitons visible in the radar images as the rips/slicks bands moving shorewards.
This work was done by financial support of RFBR Grant 96-05-65518

OA9 Basic turbulence studies

Convener: Petrosyan, A.
Co-Convener: Gerz, T.

EXPERIMENTAL EVALUATION OF KOLMOGOROV CONSTANT C0 IN THE ATMOSPHERIC SURFACE LAYER

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In the inertial subrange the Lagrangian velocity structure function is defined as $D_i^L(\tau) = C_0 \ \varepsilon \ \tau$, where ε is the TKE dissipation rate and C_0 a numerical constant. The relationship between ε, Lagrangian time scale T_L and velocity variance σ_w^2 is: $C_0 \ \varepsilon = 2\sigma_w^2/T_L$. The value of C_0 is still an open matter. In this work we present an experimental evaluation of C_0 based on surface layer wind data gathered by a sonic anemometer in a flat region in Southern Sweden. Hourly data are analysed. Wind data were firstly rotated to a streamline system, then a stationarity criterion was used to select stationary cases. σ_w^2 and the Eulerian autocorrelation function were computed and the time scale was estimated, from which T_L was obtained. Then the spectrum is estimated, from which, selecting only its part belonging to the inertial subrange, the value of ε was derived. Finally C_0 was derived from the above relationships. Its values, computed in different stability conditions, were compared to the existing theoretical estimations. It was found that our C_0 value are in good agreement with these current estimations.

EXPERIMENTAL METHOD OF ACOUSTIC TOMOGRAPHY OF THE ATMOSPHERIC SURFACE LAYER

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Acoustic tomography is proposed as a technique for remote monitoring of near surface temperature and wind fields. An experimental method is presented which provides area averaged values of the demanded meteorological parameters.
In this study travel time tomography was used by measuring the travel time of a signal at defined a propagation path between a soure and a receiver. The travel time data were inverted to obtain estimates of the meteorological parameters.
In such a system a number of sources simultaneously transmit an acoustic signal (sine oscillation) which is detected at a number of receivers. The travel time of each signal was estimated by cross correlation between the received and the transmitted signal. Each peak of the cross correlation is associated with separate ray path and the delay time corresponds to the travel time of the transmitted signal.
A field experiment was carried out in autumn 1997 at the test site Melpitz near Leipzig to provide the input data for the tomographic reconstruction. Six sources and four receivers were positioned at an array of 200 × 260 m^2. Derivations of area averaged values results from inversion of the single values of travel time for all ray paths.
Concurrently conventionally estimated meteorological quantities were used for the validation of the tomographic model and to compare the area averaged data with point measurements.

WIND - TUNNEL EXPERIMENTS OF NEUTRAL FLOW OVER SERIES OF ROUGH HILLS

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Effects of orography with horizontal and vertical scales of a few kilometres and a few hundred meters respectively, are still unresolved in NWP models and have to be parametrised. Most of the current ideas about these effects are based on linear theory and numerical simulations. The former are hindered by the assumptions made both regarding the orography and the flow and the latter produce results than in many cases are strongly dependent on the turbulence closure scheme employed.
Turbulence characteristics obtained from wind-tunnel experiments over sinusoidal topography are presented. The purpose of the experiments is to obtain quality data that can be compared with numerical results and analytical theories. Hills of both low and steep slopes (so that lee separation is expected) are considered. The surface pressure force is directly measured and compared with wavelength averaged parameters. A logarithmic profile for the wavelength averaged velocity field is supported by the experimental data.

MODIFIED k-ε TURBULENCE MODEL FOR STABLY-STRATIFIED ATMOSPHERIC BOUNDARY LAYERS

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The standard k-ε model of the turbulence closure is widespread in many applications of CFD, but has some problems for modelling of dynamics of the atmospheric boundary layers (ABL). One of the effects is that the model overestimates the turbulent length scale above the shear layer. Detering and Etling (*1985*) modified the k-ε model for neutral-stratified ABL by correction of the model constant $c'_{1\varepsilon}$ depending on the turbulent length scale and the characteristic scale for the ABL. However, for cases of the stably-stratified boundary layer (SBL) the comparison with empirical data can give non-sufficient coincidence. Using a parametrisation of the SBL height (*Zilitinkevich, 1987*) we suggest to develop the modified k-ε model for a stable stratification case. We have received the following formulation for the modified constant (a function) $c'_{1\varepsilon}$ of the k-ε model for SBL: $c'_{1\varepsilon} = c_{1\varepsilon} \dfrac{c_D k^{3/2} f^{1/2}}{\varepsilon d_h (u_* L)^{1/2}}$,
where c_D and $c_{1\varepsilon}$ are constants in the standard k-ε model, d_h is optimised by experimental data. Using a new multi-limit formulation of SBL height (*Zilitinkevich & Mironov, 1996*) the k-ε model has been developed for more complicated cases of SBL, both for flux-dominated SBL and for cupping inversion. Comparison of modelling results for several formulations of the k-ε model for SBL and measurement data has been discussed.

ATMOSPHERIC TURBULENCE AND INTERNAL BOUNDARY LAYER DEVELOPMENT IN ATHENS DURING THE MEDCAPHOT-TRACE EXPERIMENT

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An analysis of atmospheric turbulence data and profile data in Athens, Greece is presented. The data were collected during the MEDCAPHOT-TRACE Project experimental campaign in August-September 1994 covering a typical late summer period with prevailing northerly wind. The variability of the flow characteristics in the whole area was classified into three categories: northerly winds in the whole Athens basin; sea breeze throughout the whole Athens basin; and changing sea breeze (comprising partial penetration of the sea breeze over the city and/or changing wind direction throughout the day). This classification was used as basis for the investigation of the atmospheric turbulence and vertical profiles of meteorological parameters over the area. A model of the internal boundary layer height over an area with irregular coastline (Gryning and Batchvarova, Boundary-Layer Meteorology 78: 405-413, 1996) is applied for Athens during days with sea breeze and the results are in good agreement with the measurements.

MOMENTUM BALANCE-DETERMINED HEIGHT OF NEUTRAL AND STABLE IDEALISED PBL - APPLIED TO CABAUW AND LEIPZIG DATA

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The PBL height H is determined from the momentum balance with pre-set friction velocity u* by variation of H until the momentum balance equals u^{*2}, thus achieving momentum conservation. The dimensionless PBL height Hf/u* is determined as a function of the friction Rossby number u^*/fz_0 in a range from 10^3-10^{10} and has an average value of approx. 0.3 for the neutral PBL. Stability is described by the stability parameter u*/Lf over a range from 0.01 to 500, thus covering the entire stable-continuous to neutral regime. The ratio of the stable and neutral dimensionless PBL height of same friction Rossby number is determined as a function of the stability parameter.

Nieuwstadt's acoustic sounder data from Cabauw are successfully predicted within the accuracy of the measurements. The height of the Leipzig boundary layer is successfully predicted with regard to Mildner's original data. The Leipzig boundary layer was not neutral as it is usually reported. The stability parameter determined for the surface layer is 5.72.

Physical Processes in the Atmosphere near the Surface at Night

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We report on near surface observations of fast-response temperature, moisture, and three-dimensional wind velocity taken near the surface in the CASES site (Walnut River Watershed in southeastern Kansas, USA) during the Microfronts Experiment (date). We focus on clear nights when the surface inversion was strong. Two general classes of observations are considered: 1) weak winds (< 4 mps) and 2) stronger winds (> 4 mps). The objective of this study was to relate these observations to hypothesized physical processes such as density currents, breaking waves, so-called "fossil" turbulence, non-linear wave packets, and shear-driven turbulence. For this talk we focus on a gravity current episode during a period of weak winds. We show that the events that transfer substantial amounts of sensible heat are highly intermittent. Each of these events has observed "signatures" which are consistent with laboratory, heuristic descriptions, or numerical simulations of particular physical processes. We show these observations and analyses of them. We argue that, due to the highly intermittent character of the events, many observations will be needed to obtain quantitative information on the general characteristics of these physical processes which appear to be an important aspect of the nocturnal behavior of the atmospheric surface layer. Except for the shear-driven turbulence process, most operational and research numerical models of the atmosphere do not include these processes in their surface flux parameterizations. We conclude from our limited sample that events originating in the elevated inversion (well above the surface radiation inversion) that affect the surface layer are rare.

VERTICAL VARIATION IN TURBULENT STATISTICS

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Turbulence data collected at 35 and 50 m from a meteorological tower located in Catalonia, Spain, have been analyzed for two main purposes: a) To study vertical profiles of momentum flux, wind fluctuations variances, turbulence intensities, skewness and kurtosis. b) To assess residual fluctuations in order to ascertain effects attributable to the nonhomogeneous, nonstationary character of turbulence and to evaluate influences of gravity waves. Residual wind fluctuations were defined for purposes of this study as the differences between observed half-hourly average standard deviations of wind fluctuations and those that are expected to occur in association with simultaneous wind speeds and static stabilities. These latter fluctuations have been estimated developing a series of equations that present average standard deviation of the three wind fluctuations as function of two measured variables, wind speed and static stability.

THE STABLY STRATIFIED BOUNDARY LAYER OVER THE GREENLAND ICE SHEET

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The structure of the stably stratified boundary layer over the Greenland ice sheet is examined in the light of measurements carried out during the summer of 1991. The momentum transfer is shown to follow well-established similarity relations expressed in terms of the local Monin-Obukhov length scale Λ. On the other hand the transport of sensible heat appears to depart from surface-layer and local-scaling predictions. However, the evaluation of the enthalpy budget indicates that, contrary to the usual assumptions, the radiation flux divergence, the large-scale advection and the local heating/cooling rate can not be neglected. For this reason it is suggested to use u_*/N, which is similar to the buoyancy length scale, rather than Λ as scaling length. Here u_* is the friction velocity and N the Brunt-Väisälä frequency. Alternative formulations of the similarity relations based on u_*/N for both the momentum and the sensible heat transfer are proposed for use in global and mesoscale models.

MEASUREMENT OF ATMOSPHERIC WATER VAPOR FLUX IN THE NOCTURNAL URBAN BOUNDARY LAYER

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The operation of a water Raman lidar and a Doppler sodar in the central area of Rome during several nights in different seasons in the years 1994 and 1995 provided new insight on the processes of urban boundary layer. The experiment was carried out during a variety of moisture conditions and under different boundary layer forcings. The wind vectors determined by Doppler sodar and water vapor mixing ratios obtained by Raman lidar are used to deduce turbulent and mean fluxes of water vapor. The observations show that the mean vertical vapor flux is non-negligible and has values several orders of magnitude when compared to its turbulent counterpart. This is due to the fact that the observed mean vertical velocity is non-zero throughout the depth of the urban boundary layer except during the periods of free convection. The results are discussed in light of the urban heat island effect and the prevailing meso-meteorological conditions during the period of the experiment.

FIRST-ORDER CLOSURE NUMERICAL MODELLING OF THE ATMOSPHERIC BOUNDARY LAYER IN AND ABOVE A FOREST CANOPY.

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Two eddy-viscosity models describing the flow over forested ground are investigated. Both employ the mixing-length hypothesis to model an infinite horizontal domain, stretching from the ground to the top of the boundary layer. The first of these is an isothermal steady-state model, in which various mixing length parameterisations can be used. Amongst these are a shear mixing length, and mixing lengths based on the element area density of the forest. These mixing lengths are forced to tend to a limiting value as the height above the forest increases. The use of Forestry Commission field data has allowed the accuracy of these, and of the mixing-length hypothesis in general, to be assessed. The model produces accurate Reynolds' stresses, especially in the lower part of the forest, but underestimates the wind shear in the upper part of the canopy. The second model is time-dependent, and includes thermal stability effects. It is used to look at sloping forests, and once again, data is shown for comparison. Also modelled are the effects on the flow of heat exchange mechanisms such as evaporation due to radiative heating of the canopy. Results from this will be presented.

STABLE BOUNDARY LAYER HEIGHT DERIVED FROM MEASUREMENTS AND A PLANETARY BOUNDARY LAYER MODEL

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One of the main variables that describes the nocturnal boundary layer, NBL, is his depth. The knowledge of this height is very important in environmental meteorology, is a scaling parameter in similarity theory and it is a basic input parameter to meso and large scale models. During an experimental campaign carried out in Catalonia, Spain, during winter 1996, the NBL height, h, is estimated from measurements given by a Sodar Doppler and a thethersonde, and a 1-D NBL model. From the Sodar data, this height is estimated from the thermic structure parameter CT2, since one of the definitions of h, is the level where the change in the vertical gradient of CT2 (proportional to backscatter Sodar intensity), within a zone of continuous decrease is most pronunciated. Those results are compared with h estimated by the virtual potential temperature and wind profiles measured by tethersonde. All this NBL heights calculated from different measurements are compared with those given by the 1-D NBL model, in this case h is determined by taking the level at which the heat flux reaches 0.05 of the surface values. The comparison of the NBL height estimated by different methods shows quite good agreement.

EXCHANGE PROCESSES IN A VALLEY SYSTEM: THE EFFECTS OF LOCAL CIRCULATION

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Local circulations in valleys are usually dealt with as a micro- or meso- meteorological problem. Looking at the overall features of the circulations, however, the effect can be synthesized as a transport mechanism along and across the valley, and an exchange mechanism between the valley air and the atmosphere over it. In this work we shall consider both some case studies and the climatological features of a valley system (Adige Valley near Trento and Lakes Valley nearby) where a peculiar circulation occurs, often under fair weather conditions: the so called 'Ora del Garda'. This circulation is characterized by the fact that the upvalley wind which produces in the Sarca Valley appears as a strong gusty wind in the Adige Valley just north of Trento, which blows over the (low) divide between the valleys. Time series of surface data are analyzed in order to give a quantitative description of this qualitatively well-known effect; and a few case studies are reported, taking into account special observations carried out in specific sites (near the divide). The bulk circulation characteristics are interpreted in terms of hydraulic models. In this way the overall (i.e. along valley) transport features are evidenced, and the exchange among the two valleys can be estimated. On a coarse scale, these processes can be viewed as quasi-horizontal mixing processes, in conditions under which mixing is generally supposed to be inhibited.

UHF validation campaign using rawinsoundings, sodar, anemometers and disdrometer.

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A field experimental program of continuous meteorological measurements has been realised at the experimental site of the Laboratoire d'Aérologie at Lannemezan from July 1996 through April 1997. The following ground equipment were operated simultaneously: a UHF wind profiler, a sodar, two sonic anemometers at 30 and 60 m elevations, a meteorological station and a disdrometer. Simultaneously to these measurements, more than 200 radar tracking of pilot balloons and about 30 rawinsondes have been launched. The technical characteristics of this equipment allow us to use different methods of comparison for the specified characteristics of each instrument. Examples of comparison for several types of meteorological situations (strong surface wind, precipitation, thermal stability) are given and analysed with a special emphasis on the achievements and limits of the UHF profiler.

MODULATION OF SURFACE FLUXES BY ORGANIZED LARGE EDDIES

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For long time, the occurrence of Organized Large Eddies (OLE) or rolls in the lower atmosphere have been reported refering to cloud organized structures associated to the atmospheric flow (Brown, 1970). Since then, a considerable body of theoretical works and numerical simulations have been devoted to include OLE in the models (Brown 1970). Despite observational verification, there is still a lack of specific observations of flow characteristics such as OLE components, OLE lateral drift, and interactions with boundary conditions such as an inversion cap.
A problem is the observational requirements to provide relevant information with high spatial resolution, high accuracy and long time series of measurements. In the course of a field experiment (Menut et al., 1996), mean and turbulent meteorological parameters are investigated that show the presence of OLE. The measurements by Doppler lidar, sonic anemometers and sodars gave an overview of the characteristics of these OLE and sources of energy production that maintain them. The experimental results are compared to model outputs. The agreement is excellent, it shows that thermal stratification and wind shear are important factors in the structure of the OLE.

PARAMETRIZATION OF STABLE BOUNDARY LAYERS: SENSITIVITY TO STABILITY FUNCTIONS.

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A first order closure scheme is used to characterise mixing in the stable boundary layer. The eddy diffusivities are related to the local stability through functions of the gradient Richardson number. Different stability functions are compared, which allow different mixing at higher stabilities: these include the version used in the UK Meteorological Office's operational Mesoscale model and a scheme which cuts off turbulence at a critical Richardson number. The stability functions are tested in a single column model, with a fully interactive soil and surface scheme, which is forced by gradients from the Mesoscale model. The single column model was run for the site of Cardington, England, and comparisons are made with observations from the Met. Research Unit at Cardington, of both surface fluxes and tethered balloon profiles. The model's surface fluxes and mean profiles are shown to be strongly affected by the stability functions used.

TURBULENT LENGTH SCALES IN THE MARINE ATMOSPHERIC MIXED LAYER

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From aircraft measurements of turbulent wind, temperature and moisture, performed in the atmospheric mixed layer above the open ocean during the SEMAPHORE experiment, we computed the profiles of the energy-containing, integral and dissipative scales. The relationships between these three scales determine the energy spectra of the various parameters in the mixed layer. We show that all but the dissipative scales, computed on runs performed along the mean wind direction, are greater than those computed on cross-wind runs. This difference is mainly observed in the lower half of the mixed layer, i.e. the fraction which is controlled by surface fluxes. Furhermore, the scales are very different from a parameter to another: for example, the integral scale cannot be easily computed on the temperature, moisture and horizontal velocity signal, because it continuously increases as the length on the run increases, whereas, on the vertical velocity, short runs (10km) are sufficient to estimate its proper order of magnitude. On the end, we show that previous estimates of these scales, when available, agree reasonably well with our results. However, several profiles constitute original results which could be used to test the performances of the turbulence schemes (when they are based on a length-scale parameterization) in meteorological models.

CONVECTION AND THERMAL STRUCTURE IN AN ALPINE VALLEY

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The convective boundary layer which develops at the bottom and along the sides of a valley leads to typical temperature structure in a cross section, and to peculiar mixing effects. An experimental investigation has been performed in the Adige valley, near Trento (southern Alps side) using a motor-glider to determine the features of the temperature field and its time evolution during the morning. The data are temperature, pressure and humidity. The measurement results allow to guess some features of the CBL, to individuate the inversion height and the characteristics of the stable atmosphere over the inversion and below the ridge height. This experimental picture has been compared with conceptual models of the evolution of the valley atmosphere under the action of radiative heating. Some preliminary results concerning the turbulent mixing in the valley are discussed.

Mathematical model of the turbulent flow of the polluted air with the due regard of the relief of Republic of Georgia.

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The creation of the mathematical models of the atmospheric pollution is of a great importance because of the very complicated physical relief of the Republic of Georgia. The data of the model enable us to realize different projects taking into consideration all the desirable and undessirable facrors. Classical equations of the diffusion and equations of hydrodynamics were used in order to solve the given task. At the initial moment the power of the source, quantity and direction of the wind and turbulent coefficients are well-know. During the vertical calculations we took 15 layers the with step 50 m and during the horizontaly with step $\Delta x = \Delta y = 200$m.
The calculations were made parallel to the direction of the predominant wind until the conceentration of the admixtures was equated with 0,01 part of the meaning of the initial concentration. The calculations were carried out in both stationary and non- stationary regime. It was found out that in non-stationary case the weather conditions and the relief of the district have the principal meaning for the spreading of the admixtures. The spreading occurs in the spherical segment in the symmetric way towards the direction of the wind.

PROBLEMS OF AND APPROACHES TO SCALE SEPARATION USING THE EXAMPLE OF ADVECTION

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The further development of equations for a specific scale range, such as climate and weather, would save computer time and minimize sources of error. A central problem in all models is the treatment of sub-scale advection. Because of the advection can be calculated from measured data, the deficit of being unable to carrie out experiments may be campensated. For the large scale atmosphere it can be demonstrated that the usual application of Reynolds filtering for treatment of sub-scale advection in AGCMs leads to large errors. The deviations from Reynolds filtering are not distributed randomly in time.
Two new approaches to scale separation are presented and discussed. In hydrodynamics the Leonard and Mixed tensors, neglected in Reynolds filtering, are increasingly being parameterized. One of the strategies is to calculate the Leonard tensors explicitly and to parameterize only the Mixed tensors.
A completely new approach to scale separation appears to be possible if special properties of large scale dynamics are considered. It can be demonstrated that the stationary part of the atmospheric dynamics is not represented by the temporally averaged spatial variables, but by the temporally averaged spatial spectral coefficients. The last are only weakly time-dependent, in contrast to the phases. Additionally the spectral coefficients have ergodic properties. The idea is that the spectral coefficients determine the development of the climate and the phases the development of the weather.

SURFACE FLUXES VARIABILITY AND HIS INFLUENCE ON THE DEVELOPMENT OF THE PLANETARY BOUNDARY LAYER

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The first steep to understand how the surface interacts with the Planetary Boundary Layer, (PBL), is to couple relatively simple land surface models to PBL models. In this study two 1-D PBL models are coupled to a land surface parameterization models. The first PBL model applies in unstable and neutral conditions and is coupled with a surface model that consider two layers (ground +vegetation) and soil. The second PBL model applies in stable conditions and is coupled with a surface model that takes into account three layers, soil, surface and vegetation. We have simulated the evolution of the daily and nocturnal PBL over two different types of soil and vegetation, dry and irrigated agricultural areas. For each area we have considered wet to dry conditions and different fractions of vegetation density. The results show that different behavior of the superficial fluxes in response to changing surface parameters, causes important modifications on the state and development of the PBL.

ANALYSIS OF TURBULENCE MEASUREMENTS IN THE ATMOSPHERIC BOUNDARY LAYER BY UHF PROFILER, SODAR AND SONIC ANEMOMETER.

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The continuous data measured with a UHF wind profiler are examined during days for which the diurnal evolution of the convective boundary layer is well identified by classical methods (height of the boundary layer determined by rawinsonde, turbulence analysed by sonic anemometer at a height of 60 m and by sodar up to a height of 600 m). The relation between the profiles of reflectivity and spectral width and the gradients of temperature and humidity allows us in some circumstances the identification of the boundary layer upper limit. An analysis is also made at different levels of the diurnal cycle of the spectral width and of its relation with the atmospheric turbulence computed from the measurement of the vertical velocity variance made by the sonic anemometer and the sodar.

Calculation of the Turbulent Heat Flow by Means of the Gradient Method for the Mountain Terrain

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It has been already established that the mountain terrain complicates micrometeorologic regim and especially the spreading of the admixtures in turbulent medium in the surface layer of the atmosphere, turbulent heat flows were calculated by means of the gradient data for the further specification of the given question for some mountain regions of the Republic of Georgia. Humidity and the temperature of the air were measured on two levels - 0,5m and 2m, while the speed and the direction of the wind were measured on three levels - 0,5m; 2m and 4m, at the stationary . stations with due regard for the inclination of the ground surface. The experiments were carried out with one hour-interval. One could watch relatively stable temperature regime and an increase of the gradient of the air humidity on the top of the mountain against a background of the cloudless sky. According to the data of the meanings of the turbulent heat flow it was found out that the solar energy is spread irregularly and has different meanings in various mountain regions of the Republic of Georgia. It turned out that there is more solar energy (the duration of the lighting was not less than 6 hours) on the isolated area in the Eastern Georgia (Telavi - 1640 kwt.hour/m^2) than in the Western Georgia (Sukhumi - 1500 kwt.hour/m^2).

A new way to parameterize turbulence over high mountains

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The only modification of the turbulence schemes commonly used in mountainous areas is the extrapolation of the logarithmic law by the enhancement of the roughness length. Here are proposed two further modifications of the turbulence scheme itself, based on physical considerations, designed to parameterize two effects encoutered over very accidented orography:

1. the presence of deep valleys, by increasing the mixing length in the boundary layer,
2. the turbulence production by the horizontal wind shear induced by the deviation around the subgrid peaks, even high above the model surface.

These two parameterizations are used along with the classical enhancement of the roughness length. 3D simulations of realistic orographic flow observed during PYREX are then performed at meso-β scale with the MESO-NH model, with or without this 'high mountain turbulence scheme' (hmts). They show important improvements when using it, both over and around the ridge.

Finally, the model is run at meso-γ scale as a 'numerical laboratory' to simulate explicitely the turbulence, lee waves and rotors. These features compare well with the observations, and bring a first direct validation of the hmts.

SIMULATION OF METEOROLOGICAL QUANTITIES IN PLANT STANDS

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For the treatment of problems in the field of forest and agricultural meteorology an atmospheric boundary layer model containing a vegetation canopy (forest, other plants) was developed. It makes possible the simulation of essential meteorological quantities (wind, air temperature, atmospheric humidity) as well as turbulent energy fluxes and other turbulence characteristics within and above large-area forest canopies. The model is also applicable to lower-grown plant stands (i. e. agricultural ones) where any stand density, degree of plant covering and specific parameters for vegetation and soil can be prescribed. Simulation models of this type are sufficiently characterized by their very high vertical resolution (above 50 computational levels in the lowest 20 meters, 120 levels between 0 m and the upper boundary of the model domain at 2000 m). The vertical resolution is an important characteristic feature compared to other model classes (big-leaf models, mesoscale simulation models). Furthermore the numerical expense is much smaller than the one for mesoscale models. Numerous numerical experiments have been carried out with various turbulence closure assumptions for different seasons and foliage conditions. The characteristic features of the simulated quantities mentioned including the biomass temperature are reproduced in a good general agreement with observations.

A PROGNOSTIC PARAMETERIZATION OF THE TRANSILIENT TURBULENCE MATRIX FOR NON-LOCAL CLOSURE

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A variety of turbulence closure models have been developed that relate turbulent dispersion and mixing to non-local properties of the turbulent flow.
The Transilient Turbulence (TT) closure model employs a non-local definition of turbulent fluxes and produces non-local mixing of physical quantities. Admitting the advective character of turbulent dispersion, the basic assumption of TT states that in certain conditions a matrix operator, called the Transilient Matrix (TM), may be used to represent the process of non-local turbulent mixing.
The previously developed parameterizations of TM are diagnostic; i.e., they defined the amount of non-local mixing based on the current state of the atmosphere. The most recent one used a diagnostic formula based on non-local analogue of the turbulence kinetic energy (TKE) budget equation. Proposed here is a prognostic, 1.5 order, version utilizing a non-local analogue of the TKE budget equation. Hence, it takes into account the evolution of the turbulence and its influence on the turbulent state of the atmospheric flow.
We will introduce the main ideas and proposed prognostic formulation of the TM parameterization. Then we will present the results of simulations, using a simple dispersion model, for which we will consider idealized cases with different types of forcing conditions and different types of atmospheric stability. Finally we will discuss turbulent dispersion and evolution of PBL as predicted by TT.

THE CLOUDY BOUNDARY LAYER FLOWS VISUALISATION.

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The new approach to the problem of the cloudy boundary layer flow visualization and studies was developed. We have examined the sequence of cloudy layer images such as hurricanes and tropical storms in order to reconstruct the 2D- velocity field. We have used the Adaptive Least- Square Matching technique in order to reconstruct the 2D-velocity field. This method allows us to proceed the analyze at different scales with good availability control. Although our analyze was based on cloud movements, so we can tell only about "cloud-based" velocity, this results are meanful in relation with impurity translations. This technique has great potential, because using couple of satellite images (stereopair) we will be able to reconstruct 3D-velocity field. The first results on reconstruction of tropical storm flows will be discussed in our presentation.

Characterization of atmospheric turbulence by the collective wave scattering approach

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ST radars are commonly used to study atmospheric turbulence from the power or the width of the Doppler spectrum, for example by determining the structure constant C_n^2 or the energy dissipation rate, ϵ. An original approach, based on the theory of the collective diffusion and a Lagrangian description of the diffusion center's motion, gives us an analytical form of the autocorrelation function and therefore of the Doppler spectrum, its Fourier transform. Considering the 'beam-width broadening' of the radar and the mean wind, we can fit them and directly obtain the eddy diffusion coefficient, the correlation time and the power spectrum of the index fluctuations ($\Phi_n(k)$). Knowing $\Phi_n(k)$ we may deduce the C_n^2, L_0 the outer scale and l_0 the inner scale. We shall present results and we shall compare them with the values obtained by usual methods.

STUDY OF THE ATMOSPHERIC STABILITY BY USING A 9 M METEOROLOGICAL MAST

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In this work the first results obtained with the use of a 9-m meteorological mast are presented. This small tower is located in Villafría (Burgos, Spain), in a flat semi-urban terrain. Wind speed, wind direction, air temperature and relative humidity sensors are placed at three heights; also, global and net radiation, atmospheric pressure, soil heat flux and three soil temperatures are measured. The atmospheric turbulence structure of the surface layer has been studied with this set of instruments. After the calculation of the roughness length in neutral conditions, the main turbulent parameters of the surface and boundary layer have been evaluated with the use of the wind, temperature and humidity profiles in different stability conditions. The transition from a stable to unstable surface layer is studied in the particular case of an autumn single-night radiation fog.

BOTTOM BOUNDARY LAYER IN THE BLACK SEA

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Specialized complex OLT-D for vertical profiling of currents and hydrologic characteristics in near-bottom area was created in the MHI NASU. Experimental researches were executed in the shelf zone and in the deep-water regions of the Sea. Data processing and attraction of archival materials have shown the significant diversity of structural BBL features. Turbulence stipulated by the shifts of the near-bottom currents playes the main role in the BBL formation on the shelf zone. Positive vertical gradients of temperature and salinity are observed in many regions and it creates the conditions for developments of the differental-diffusion convection processes. The estimates were shown that their contributions in the vertical flows considerably smaller then the shift turbulence contribution. Near-bottom thermal convection layer with the thickness to 500 - 550 m (average significance about 300 m) is formed in the deep-water part of the Black Sea under action of the geothermal flows and inducting convection turbulence. Diffusive boundary layer with thickness from 30-50 to 100-120 m is observed on the BBL top border. Differental-diffusive processes develop in this layer forming its fine-structural stratification. These processes largely provide the balance between geothermal flow and heat flow through top BBL border. The dependence of the BBL thickness from the geothermal flow correspondent to the known Turner's model (1968) at account of the effect of the Earth rotation on the convection instability development in the diffusive layer.

USE OF FOKKER-PLANK EQUATION FOR PARAMETERIZATION OF TURBULENT DIFFUSION OF GAS-AEROSOL POLLUTION IN ATMOSPHERE.

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Here are considered the conditions, in which turbulent diffusion of gas-aerosol pollution can be approximated by random Markov process in co-ordinate and velocity space of turbulent mole (random field of accelerations is supposed delta-correlation). There was formulated Fokker-Plank equation for parameterization of turbulent diffusion in co-ordinate and velocity space.

There was obtained functional transformation of Fokker-Plank equation, which allows to make its analysis one of usual equation of turbulent diffusion, for which the turbulent exchange is parameterized with help of well-known gradient approximation.

There were obtained analytical solutions of Fokker-Plank equation for problem on turbulent diffusion of gas-aerosol pollution in atmosphere taking into account the underlying surface influence and also sedimentation, physical-chemical transformation and horizontal transfer of particles. In obtained solutions for the first time there was considered the influence of LaGrange scale of atmosphere vertical turbulence.

THEORETICAL STUDY OF ACOUSTIC TOMOGRAPHY INSIDE THE ATMOSPHERIC BOUNDARY LAYER

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The method of acoustic tomography will be transferred on the turbulent atmosphere in order to directly provide area averaged values of meteorological quantities, especially air temperature, needed for evaluation of Large Eddy Simulations and micro-scale Atmospheric Boundary Layer models.

Sound waves propagate through the atmosphere with different sound velocities according to the distribution of air temperature and wind vector caused, e.g., by the environmental conditions. Therefore, sound waves become a carrier of information and lead to a spatial description of the medium properties.

In the presented study measured acoustic travel time data between 6 sources and 4 receivers, set up in an experimental array of 260×200 m^2 over grassland (Melpitz Experiment '97), were used as initial values for acoustic tomography.

A frequently used procedure of ray tomography, the Simultaneous Iterative Reconstruction Technique (SIRT), characterised by simple handling and small computational time requirements will be applied.

To estimate the general sound ray propagation through the atmosphere during various meteorological situations and the difference to an approximation of horizontally straight ray propagation a ray tracing model based on a modified version of Snell's law corresponding to the influence of wind vector will be introduced which requires vertically high resoluted temperature and wind profiles.

A NEW CONCEPT OF THE 3rd ORDER TRANSPORT AND NON-LOCAL TURBULENCE CLOSURES FOR CONVECTIVE BOUNDARY LAYERS (CBLs)

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A new advection + diffusion parameterization for the flux of flux of potential temperature is developed with due regard to the bottom-up/top-down asymmetry of the semi-organised buoyancy-driven structures in the CBL. Next, working out the heat-flux budget equation, a non-local turbulence closure is derived. The latter is shown to be in excellent correspondence with large-eddy simulation (LES) of the CBL. In particular cases it reduces to the counter-gradient, transport-asymmetry and integral closure schemes proposed earlier. It provides mathematically rigorous procedure for the decomposition of the heat flux into the bottom-up and top-down components

A PROGNOSTIC EQUATION FOR THE DEPTH OF EVOLVING STABLY STRATIFIED ATMOSPHERIC PLANETARY BOUNDARY LAYERS

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A prognostic equation for the depth of the stably stratified planetary boundary layer (SBL) is derived from scaling analysis of the non-steady turbulence kinetic energy budget with due regard to the earth rotation, the surface buoyancy flux, the static stability of the free flow, and the large-scale rising or subsidence. In the steady state the equation reduces to a multi-limit, equilibrium SBL depth formulation. In different non-steady regimes the SBL relaxation time scale depends on different governing parameters. It is shown to be typically of order several hours for the most of atmospheric SBLs. The SBL growth and decay predicted by the proposed prognostic equation are compared with what follows from turbulence-closure and bulk-Richardson-number models, and also with available field data. Possible implementation of the proposed SBL-depth equation in atmospheric models is briefly discussed.

OA10 Fluxes over terrestrial surfaces

Convener: Jensen, N.O.

01 Surface fluxes in non-homogeneous terrain

Convener: Foken, T.

Estimating potential evaporation over a hill

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The effect of orography on the potential evaporation is studied numerically and analytically. In some thermodynamic regimes (warm and wet) potential evaporation can drop by 30 percent over a 300m hill. On the other hand, the increase in surface area in hilly terrain can cause the potential evaporation to increase, even when the reduction in available energy per unit surface area is taken into account. If the average slope of the hill is 30 degrees, the increase in potential evaporation can be as much as 10 percent. Present methods for estimating the effect of orography on potential evaporation in meteorological and hydrological models correctly predict the effect of adiabatic cooling, but ignore the effect of the increase in surface area.

SENSIBLE HEAT FLUX AND RADIOMETRIC SURFACE TEMPERATURE OVER SPARSE VEGETATION IN A SEMIARID REGION

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The demand for spatial distributions of surface fluxes requires the use of remote sensing. Sensible heat fluxes can be estimated from knowledge of surface temperatures measured at the thermal infrared wavelengths. These kinds of methods require also a measure of air temperature. The estimation of the sensible heat flux from these two temperatures requires an estimate of the excess resistance to be added to the aerodynamic resistance to the transfer of heat from the surface. Earlier studies have provided different evaluations of this term. In this work, we analyse this excess resistance using data acquired over sparse vegetation in a semiarid region. The study area is located in a semiarid basin in south-eastern Spain. Data used in this study correspond to the first three months of a field campaign that started in August 1997. The turbulent surface fluxes have been measured using an eddy correlation system and averaged over twenty minute periods. The system includes a three axis sonic anemometer (CSAT-3) with a fine wire thermocouple. In this way we obtain estimates of sensible heat flux and friction velocity. The last is a necessary input for the aerodynamic resistance. The radiometric surface temperature was measured using Everest Interscience model 4000 infrared thermometer detecting in the 8-14 micron waveband.

Surface fluxes, turbulent moments and characteristic scales of a tropical forest, a tropical savanah and a Sahelian savanah in Africa.

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Fluxes of sensible heat and latent heat were collected by aircraft during two international experiment, in two different areas in Africa : HAPEX-Sahel 1992 in Niger (14 degrees N) and EXPRESSO 1996 (5 degrees N) at the boundary between Congo and Central-Africa. The first was devoted to the estimation of the surface energy budget at a regional scale in a sahelian boundary layer whereas the second was aimed at estimating the dynamical and chemical exchanges between the tropical forest and the savanah. The turbulent characteristic of the boundary layers are compared in relation with the surface variability. Both boundary layers are forced by similar large-scale atmospheric circulations linked to the progression of the Intertropical Convergence Zones (ITCZ). According to the position of the ITCZ relative to the area of study, the surface layer and a part or the whole of the boundary layer is controlled by the south-west flows of the Monsoon (warm and moist) whereas the upper layers are driven by the north-east warmer and drier flows of the Harmattan. So, the difference in the Bowen ratios that is expected owing to the different surface covers in both experiments can also be examined with respect to the synoptic scale conditions. Special attention will be drawn to the influence of the large scales at the top of the boundary layer on the surface momenta, to show that the problem of spatial averaging of the surface fluxes not only requires a good knowledge of the surface variability but also of the whole boundary layer structure.

FLUXES OVER HETEROGENEOUS LAND SURFACES - THE LITFASS-1998 EXPERIMENT

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The German Weather Service (DWD) currently runs a five-year research program (LITFASS) in order to determine the area-averaged turbulent fluxes of energy and momentum over a heterogeneous landscape around Lindenberg. These fluxes shall be representative for a horizontal scale of about 10 km (while the typical patch scale is between 10^2 to 10^3 m) corresponding to the size of a grid cell in the present operational NWP model of the DWD. The LITFASS-project is closely related to the BALTEX program since the topography around Lindenberg is typical for larger regions of eastern Central Europe and hence for a major part of the southern BALTEX area.
In May-June 1998, a field experiment will be carried out in the Lindenberg area. Turbulent fluxes which are representative for different horizontal scales will be derived from eddy-correlation measurements over different types of land surfaces, from spatially integrating scintillometer measurements of structure function parameters, from remote sensing data, and from airborne measurements using the HELIPOD sonde and high-resolution aircraft instrumentation. Vertical profiles of meteorological parameters across the ABL will be provided from continuous operation of sodar, wind profiler, RASS, and lidar systems. The paper shall present details of the experiment design and of the data evaluation strategy.

REGIONAL ENERGY FLUX MEASUREMENTS AND MODELLING ALONG A RAINFALL GRADIENT IN AUSTRALIA

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There is a continuing need for models of land-atmosphere interaction at scales from patch to region, to serve the requirements of atmospheric models for terrestrial lower boundary conditions, and the needs of hydrological models for descriptions of the water flux between soil and atmosphere. The Snow-Soil-Canopy-Atmosphere Model (SSCAM) is a model designed to include all relevant physical and biological processes. Special attention is paid to aerodynamic processes. Simulations are made of fluxes measured during OASIS (Observations At Several Interacting Scales), a large-scale experiment on energy and trace gas exchanges in a heterogeneous landscape near Wagga Wagga, NSW, Australia. Energy flux data are available from several sites with different vegetation covers (pasture, wheat, oats and triticale) along a transect of length 100 km, over a three-week period in October 1995. The mean annual rainfall is 550 mm at Wagga Wagga and decreases westward by about 1 mm per km. The regional scale energy fluxes are simulated using the three-dimensional Division of Atmospheric Research Limited Area Model (DARLAM) with SSCAM as a lower boundary condition, accounting for heterogeneity in vegetation cover and soil type.

Scaling of CO_2 and CH_4 fluxes from chambers to landscape scale.

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During summer season of 1997 fluxes of carbon dioxide and methane were measured over an extensive fen and a neighbouring heath area in northeastern Greenland. The size of the fen area provided almost optimal fetch conditions for the eddy correlation measurements, but also over this type of surface variation in fluxes could be related to differences in wind direction an source areas. Also the chamber measurements reflected the small scale differences in vegetation composition ranging from wet dominated arctic cotton grass (*Eriophorum sceuchzeri*) to the more dry species of dwarf shrubs (e.g. *Cassiope tetragona* and *Vaccinium uliginosum*). Here we show how the local heterogeneities found in the chamber measurements are related to eddy correlation measurements. Further we demonstrate how eddy correlation measurements made over two different surfaces at low level can be integrated in higher level eddy correlation measurements. An interpretation of the differences found in the fluxes, is based on a classification of the fen area depending on vegetation types in the source area.

A NUMERICAL CASE STUDY ON THE SENSITIVITY OF THE WATER AND ENERGY FLUXES TO THE HETEROGENEITY OF THE DISTRIBUTION OF LAND USE

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Numerical experiments assuming land use distributions of different heterogeneity of wet and dry surfaces were performed for a cloudy day in springtime with calm wind to examine their influence on the domain averaged fluxes as well as on the distribution of the fluxes within the domain. The results substantiate that for large heterogeneity, i.e., small patches the distribution of the patches plays no role for the magnitude of the atmospheric fluxes. For larger patches, however, the domain averaged latent heat fluxes appreciably depend on both the heterogeneity as well as on the fractional coverage by the land use types. On the average, for heterogeneous conditions the prevailing land use type governs the fluxes. Nevertheless, no exact linearity between the fractional coverage of the two land use types and the resulting fluxes exists. Discontinuities in the fluxes, which lead to the non-linear behavior of the domain averaged fluxes, occur at the border between two larger areas of (extremely) different characteristics, namely, *grass* (wet, cool) and *sand* (dry, warm). Three different behaviors were found for the temporal development of the differences in the domain averaged fluxes which depend on both the heterogeneity and the pattern of the land use.

COMBINED ATMO-RADIOGEOCHEMICHAL SURVEY AND MONITORING OF MANIFESTATIONS OF ENDOGENOUS PROCESSES

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Considered is a combine atmo-radiogeochemical technology for studying geodynamic state of the Earth crust, its manifestations in the newest earth degassing processes, revealing and ranking deconsolidated permeable zones in their fluid conductivity and with due regard of their radiochemical features and HC-breathing, building model of the structural geodynamic frame, and prompt prediction of possible oil and gas accumulations. Scientific basics of this technology are the newest data about the ascending migration of fluids from deep lithosphere zones, their geochemical characterization, and role they play in the origin of geochemical and geophysical anomalies and formation of pools inside the fluid invasion "haloes." The technology assumes simultaneous acquisition of multiparameter geochemical and geophysical data (distribution of CH4, radon measured at the altitude of 50-75m) by means of atmo-geochemical airborne survey combined with the -ray spectrometry, thermal, electromagnetic, and magnetometric surveys.. Equipment includes optical laser HC-analyzers. -ray spectrometers, etc. This combination allows to study the block structure of a geological medium, build geological structural models, implement zoning of the area under study by the fluid- conductivity and examine manifestations of deep processes in the landscape and near-surface atmosphere. Monitoring of active geodynamic zones to predict their evolution and hazards is discussed. Technology applications to the Tatarstan and East Siberia areas are presented.

Effect of Soil Moisture on the Diurnal Variability of the Atmospheric Boundary Layer

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We report on preliminary results of the first field expedition to the Cooperative Surface Atmosphere Exchange Studies (CASES) site at the Walnut River Watershed in southeastern Kansas (USA) during the period 22 April to 22 May 1997 (CASES-97). The objectives of the expedition were: 1) to observe the effect of soil moisture on the diurnal behavior of the atmospheric boundary layer, 2) test the effect of patchy soil moisture on the exchange coefficients in bulk transfer formulae, and 3) to insure that the wind-RASS profiler network forming the backbone of CASES was of sufficient accuracy to evaluate the rate of change and advection terms of the budgets of virtual temperature and momentum. CASES-97 deployed 3 temporary rawinsonde systems, 12 surface flux towers, 2 flux aircraft, and a special radar to the CASES site. We will briefly describe the experimental design and meteorological context of the observations. Then we will present observations and budget analyses which will describe the effect of soil moisture on the growth of the boundary layer. We will compare two fair-weather cases: 1) one that followed a modest rain event two days earlier and thus was in a period of dry down and 2) one that followed a strong rain event the previous day and thus represented saturated conditions.

DESERT SToRMS: A FIELD AND LABORATORY INTER-COMPARISON OFMETHODS UTILIZED FOR MEASUREMENT OF MERCURY FLUX FROM TERRESTRIAL LANDSCAPES

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From September 1-5, 1997 scientists from Sweden, Germany, Canada and the United States representing 10 research institutions convened in Reno, Nevada, USA to measure mercury flux from a naturally mercury-enriched terrestrial site. Four micrometeorological techniques and seven field flux chambers were used to measure in situ mercury flux. A laboratory gas exchange chamber was utilized to measure flux from soils collected from field chamber sites. Responses in micrometeorological and field chamber fluxes to environmental conditions were similar. However, the magnitude of the fluxes calculated using micrometeorological methods were up to an order of magnitude higher than those obtained using field chambers. Fluxes measured in the laboratory were slightly less than those measured in the field. Field chamber results were influenced by substrate and chamber characteristics, and sampling parameters. Although there was much more variation in fluxes measured with micrometeorological techniques consistent ranges for specific environmental conditions were exhibited and a diel pattern persisted. All sampling methods recorded a significant increase in mercury flux in response to a rainfall event.

SURFACE FLUX OBSERVATIONS USING REMOTELY PILOTED AIRCRAFT - INITIAL RESULTS

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Experiments performed within the EU-funded ReSeDA project near Avignon, France, in June 1997 involved detailed measurements of atmospheric temperature and humidity over agricultural fields using a small remotely-piloted aircraft. The objective of the aircraft experiments was to observe directly fluxes of heat and moisture above the different surface types and their blending in the atmosphere.

The aircraft, instrumentation and operations are described, followed by a discussion of the experiments and the data preparation and analysis. The work highlights several practical issues (operations and instrumentation) relevant to the use of unmanned aircraft in such experiments.

Preliminary results from the experiments are described. Near the surface (< 3 m), contrasting atmospheric conditions (especially humidity) over different surfaces are observed, and as expected the contrast diminishes with height. It is not clear to what degree the observations can be used quantitatively rather than merely qualitatively. The experience and data from these experiments help clarify the role and potential of such aircraft for studies of land surface / atmosphere processes.

OA10

THE FETCH REQUIREMENTS FOR PROFILE AND BOWEN-RATIO MEASUREMENTS OF SCALAR FLUXES

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The upwind extent of uniform fetch required for accurate measurement of scalar fluxes is determined for the flux-profile and Bowen-ratio measurement techniques. The fetch required for flux-profile measurements is similar to that for eddy-correlation flux measurements which are made at a height equal to the average of the upper and lower profile measurement heights. An identical requirement is found for the Bowen-ratio/surface-energy-budget technique only in the very limited case of a horizontally-homogeneous turbulent flow field and a spatially-uniform flux of available energy. When the flux of available energy is non-homogeneous, the fetch requirements are, in many circumstances, reduced (increased) for a surface flux that has a spatial distribution which changes in the same (opposite) sense as the available energy flux.

PARAMETRIZATION OF LOCAL ADVECTION INFLUENCE ON WATER TRANSPORT

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The concepts reviewed up to this point are to quantify the influence of local advection of dry air on moisture characteristics and on evapotranspiration in atmosphere surface layer. It is assumed the evapotranspiration from a uniformly-moist surface of limited size, such as an irrigated field, which temperature and roughness are uniform and the same as the surrounding presumably drier land surface. The changes in surface conditions are frequent and it gives rise to inhomogeneity, which influences on the conditions in the atmosphere surface layer. There were modelling the influence of the advection effects near changes in surface conditions on the evapotranspiration from canopy surfaces of the different roughness length z_0 at the weak, gentle, and strong flow of the air. There was modelling also the horizontal and vertical variability of the normalized specific humidity by local advection.
It was manifested that the followed evapotranspiration values decrease by the local advection of the dry air and this decrease is very expressive above rougher surface and at the strong flow.

SURFACE HEATFLUX EXTRAPOLATED FROM SODAR-DERIVED HEATFLUX PROFILES

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Surface heatflux is an important input parameter to local diffusion models. Estimation of sensible heatflux profiles is possible, provided similarity theory under convective conditions is valid. Using this assumption, Weill et al. (1980) developed a method to estimate sensible heatfluxes from vertical velocity variance. This method was tested using Sodar measurements performed during the POLLUMET (POLLUtion and METeorology) field campaign at the Bernese Seeland, Switzerland. Additionally, the heatflux profiles were compared to aircraft data. Surface heatflux values were deduced by extrapolating the linear profiles and surface measurements obtained from sonic systems. The Sodar results compared favourably with data of the other instruments. The examples seem to indicate that the method is surprisingly well suited to determine surface heatflux and heatflux profiles even when the assumption of homogeneity is violated.

LAND SURFACE PARAMETERIZATION MODEL. COMPARISON WITH MEASUREMENTS

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A simple parameterization of land surface processes, proposed by Noilhan and Planton, that was a simplified version of Deardorff's model, is used in order to calculate turbulent surface fluxes. The model compute five prognostic variables: the surface temperature, (representative of both, canopy and soil surface), the deep ground temperature, the interception reservoir, the superficial soil moisture, and the deep soil moisture. The turbulent surface fluxes are calculated with the classical aerodynamic formulas that includes beside other parameters, this prognostic variables. An exhaustive study of the sensitivity of the surface fluxes to surface variables and parameters have been done. We have attempted to compare this computed turbulent surface fluxes, for the whole system ground vegetation, with several observed surface fluxes. The measurements were carried out over two types of soil and vegetation corresponding to dry and irrigated agricultural areas, since we have one year of continuous measurements. The comparison give quite agreement between computed and observed turbulent fluxes.

Evaluation of the time-step effect on model results by using the modified Shuttleworth-Wallace evaporation model

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SVAT models represent small-scale processes and thus, they are local models. Integration of biosphere-atmosphere exchange, vegetation dynamics and hydrological processes in space and time is at present one of the most actual research tasks. When moving toward larger scales, one of the methods to study the problems of scale is to conduct numerical experimentation studies, i.e. to compare the simulations done with detailed models to simulations with simple parameterisations. In this way one can identify the effect of simplifying and averaging, in time and space, of the processes. The modified two-layer Shuttleworth-Wallace evaporation model was tested on several types of vegetation and it showed a good performance in modelling energy fluxes and soil moisture. Therefore the model was used as a tool to investigate if the daily time step of model, using daily values of meteorological variables, could reproduce the summed hourly measured fluxes. The model was validated against e! nergy fluxes and soil moisture of two boreal forests, i Norunda (Central Sweden) and i Flakaliden (Northen Sweden), both within the EUROFLUX project.

Large Eddy Simulation in Neutral Stratification over Inhomogeneous Vegetation Canopy

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For simulation studies over inhomogeneous surfaces, a model should first be tested over homogeneous surfaces. As a result of such an exercise, it is shown that for a simple Smagorinsky model, "logarithmic" velocity profiles, which are consistent in slope with the prediction from Rossby number similarity, can be produced, given the model parameters are carefully selected. This sensitivity to the subgrid model is further shown to be a consequence of the relation between dominant spatial scales of a neutral flow and the filter length invoked in a LES.

The influence of different model setups, as discussed for the neutral flow, is then investigated for an inhomogeneous surface with varying canopy characteristics. It is found that in particular quantities such as the effective roughness length or scalar fluxes, are markedly affected.

Influence of roughness change on the profiles of mean wind and momentum flux observed in the neutral surface layer.

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Two different surface-flow modifications as induced by a roughness change: (a) from bare soil to tall grass (smooth - rough) and (b) from wheat to short grass (rough - smooth), in neutral conditions, observed from within the same period of two consecutive years (1996 and 1997) at an experimental site near Lindenberg, Germany, during the phases of LINEX field campaigns is reported in this work. The mean and eddy correlation instrumentation used for these observations, were positioned at the middle of the eastern flank for the 'figure 7' shaped measurement field and thus presenting fetches ranging between 140 m and 250 m, which is also dependent upon the direction of prevailing westerly winds. The mean wind profiles which were obtained from a 10 m mast indicated the prominence of internal boundary layers (IBL) caused by the step change of the surface roughness andcan be represented by an empirical relationship of the form: $d\delta = a . x b$, where $d\delta$ is the IBL depth, x is the fetch, and a, b are constants. The ratio of friction velocities below and above the IBL, u*2/u*1, as determined from a two-level (2 m and 5 m) eddy correlation measurements, indicated that between the two levels there was a significant difference of about 15% for the momentum flux. Also from the LINEX data, we have shown that a quantitative relationship, of a fairly exponential behaviour exists between this ratio and the dimensionless fetch, x/zo.

VARIATION OF THE SURFACE TEMPERATURE AND THE CLOSURE OF THE ENERGY BALANCE OF THE SURFACE LAYER

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The data from the field experiments: Carpenter-90 and LINEX-97/1, have been analysed to investigate for the energy exchanges between the atmospheric surface layer and the underlying surface. In the dataset, all the components of the energy balance equation – both the shortwave and longwave radiation, the turbulent fluxes of sensible and latent heat at 2 m height, the heat flux into the soil, the surface temperature, and the profiles of the soil temperature (LINEX-97/1) were measured. These measurements which were continuously made over several days indicated that the exchange of energy between the atmosphere and the surface mostly is a non steady state process. The surface temperature measured by use of an IR-thermometer and the soil temperature profiles as well as the soil heat flux averaged over periods of 5 minutes were analysed. The soil heat storage is sometimes observed to reach about 30 % of the magnitude of the net radiation. It can be shown that the non-closure of the surface energy balance obtained which is about 15 to 20 % can be reduced to a value lower than 5% at an ideal measuring site. These results suggest that the non steady state part of the energy balance equation is important and introduces a significant error in indirect methods for the determination of the turbulent fluxes such as the Bowen-ratio method.

ON SCALAR SURFACE FLUX AGGREGATION IN HETEROGENEOUS LANDSCAPES

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Due to the variations in land-use, and the resulting patchiness, surface fluxes need to be aggregated before they can be used in larger scale models. Because of the nonlinear nature of the relevant physics it is not correct to do this by any type of a simple averaging procedure, especially not for the surface roughnesses and the resulting friction velocity u_*. The problem is well-known. The more frequent the surface change the worse the problem. The air has no possibility of "forgetting the past" and adjust to local conditions. The patch scale would need to be as large as many tens of kilometres to allow for a simple fractional average of the equilibrium fluxes pertaining to each surface type. The paper describes an objective and fast aggregation method for scalar surface fluxes. The method is based on the model for momentum-flux aggregation described in Hasager (1997, Risoe-Report-922). The model is useful in real terrain with variations in aerodynamic roughness, surface temperature and/or surface humidity.

UNEQUAL EDDY DIFFUSIVITIES OF HEAT AND WATER VAPOUR AT THE BASE OF AN ADVECTIVE INVERSION

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Many approaches to model surface fluxes of scalars, and some measurement techniques too, assume their eddy diffusivities to be equal. Occasionally however, unequal diffusivities of heat (K_T) and water vapour (K_q) have been found. Especially in the extreme case of an advective inversion ("oasis"), results have been contradictory. To understand this, we suggest a mechanism that relies on slow variations of the mean windspeed u. Periods of high u are associated with a high saturation deficit at crop height, thus driving strong evaporation, while calmer periods produce lower deficits and thus lower evaporation. This wind-deficit-correlation adds a non-linearity to the diffusivity ratio, K_T/K_q, with the effect that its temporal averages can deviate from one although the momentary values do not.
We tested our suggestion over a rice paddy adjoining to dry land. Well behind the dry-to-wet transition (fetch-height-ratio > 100:1), fluxes and gradients of heat and water vapour were measured simultaneously. Winds were often light and variable due to PBL-scale convection over the dry upwind plane. In these conditions K_T/K_q was typically somewhat greater than one, in agreement with our predictions.

VERTICAL EVOLUTION OF TURBULENT CLOUDWATER FLUXES ABOVE FOREST

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Eddy correlation measurements of cloudwater fluxes were made concurrently at two heights over a forest canopy near the Pacific coast of North America. Surface-normal cloudwater fluxes at 10 and 15 m above the ground consistently were seen to diverge, often with a change in the sign of the flux between the two measurement heights. This flux divergence is significant relative to measurement errors determined from instrument intercomparison. The flux divergence is shown to be due to the influence of an atmospheric source term for this non-conservative scalar: condensation in the mean updrafts that drive orographic cloud. Accounting for the change in flux with height is shown to be important for estimation of canopy uptake of cloudwater and chemicals via occult (droplet) deposition. This study shows the utility of surface-layer budget equations for describing differences between true surface fluxes and those measured in the atmosphere.

REGIONAL-SCALE CO2 FLUXES OVER CENTRAL SWEDEN BY A BOUNDARY LAYER BUDGET METHOD

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Measurements of CO2 flux and concentration were made on a 100 m tower in an area of mixed pine and spruce forest near Uppsala in central Sweden. Free-flight radiosondes were used to measure the height of the convective boundary layer (CBL) over four days. The mass balance equations developed by Raupach et al. (1992) were applied to calculate fluxes of CO2. The method exploits temporal variations in CO2 concentration in the CBL which is well mixed and treats the CBL as a large chamber within which conservation of mass applies. The method yields cumulative surface fluxes over the trajectory of an air column crossing the landscape, with source areas of the order of 10 to 100 km2, depending on the time interval used. These flux estimates were compared with the ecosystem-scale fluxes measured by eddy covariance at the same site. Reasonable agreement was found, given the differences in source area. The greatest difficulty with the method is in the estimation of CO2 concentration above the CBL. Further tests of the method are needed, preferably against aircraft flux measurements. The method is valuable as an independent measure of regional-scale surface fluxes, and provides a check on the representativeness of eddy covariance measurements as a sample of the wider region. The CBL budget method is potentially valuable in scaling up work as it would allow us to evaluate different summation procedures using eddy covariance measurements of fluxes in the different vegetation types, and evaluate averaging schemes for parameters derived from ground-based flux measurements, such as surface conductance and photosynthetic capacity.

MODELLING THE PARTITIONING OF THE EVAPORATION FROM A HETEROGENOUS MILLET CROP IN BURKINA FASO

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Facing the problems of using evaporation models developed for homogenously vegetated surfaces in sparsely vegetated ones, modelling of evaporation from the latter environment has received more attention over the last decade.

During the growth seasons 1996 and 1997 evaporation measurements in a sparsely covered millet field in northern Burkina Faso were conducted using the eddy correlation technic and sap flow measurements as references for modelling the partitioning of evaporation between plants and bare soil. Additional measurements of standard climatological parameters were collected as well as measurements in the vegetation stand such as LAI and stomatal conductance. Measured and modelled results from selected days which indicate the large variation between plant- and bare soil contributions are presented and the ability of the models to describe the total evaporation in this two component system is evaluated.

TRACER EXPERIMENT OVER A TALL CANOPY

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Most often, sites vary spatially in their physical, chemical or physiological source characteristics, making the interpretation of eddy-correlation fluxes and/or scalar concen- tration measurements spatially variable even for the same site, depending on the time of day, the seasonal climatology, and the atmospheric stability. Lagrangian models are intrinsically more versatile than analytical solutions but must be tested over tall rough vegetation canopies before being used with confidence. A tracer experiment was performed over a peach orchard to validate a Lagrangian model of 'footprints', i.e. to validate predictions of the weighted spatial extent of upwind contribution from upwind sources to a point flux measurement. Results are discussed.

MOMENTUM FLUXES DUE TO SUB-GRID SCALE OROGRAPHIC EFFECTS

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The horizontal length scale of non-ideal mesoscale terrain features, impedes its realistic representation in numerical weather prediction models. The generation of gravity waves with wavelengths that allow for the vertical transport of energy and momentum are one of the possible effects of sub-grid scale orography. These waves are responsible for dramatic changes in the flow around these mountains, and also in altitude. Because the importance of the representation of these effects is well recognised most large scale models include a parameterisation of its effects in the mean flow. In linear flow, the drag on the mountain due to an asymmetry of the pressure field around it is equal to the upward flux of momentum due to gravity waves. That vertical flux of horizontal momentum transports the influence of the surface orographic features into the atmospheric flow. The present study uses data from a field experiment in the Island of Madeira to evaluate the performance of simple parameterisation schemes that are currently used when compared with models that use a complete representation of the real orography.

INFLUENCE OF VEGETATION COVER HETEROGENEITY ON THE SPECTRAL COMPOSITION OF UP- AND DOWNWARD DIRECTED RADIATIVE FLUXES.

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The spectral composition of up- and downward directed solar radiation fluxes in Vegetation Canopy is of great interest for photosynthetical, airchemical etc. studies and for the Remote Sensing. The features of incoming and transformed by vegatation fluxes are determined by three main parameter groups: (i) illumination conditions i.e Solar elevation angle, atmospheric turbidity, cloudiness; (ii) optical properties of phytoelements and soils and (iii) structure of vegetation canopy. To evaluate the influence of latter two parameters we used the three-dimensional radiative transfer model, developed in Institute of Bioclimatology, Uni Goettingen. The results of sumilations werecompared with measurements of spectral compositition of solar radiation transmitted by a spruce forest canopy.

VERTICAL FLUXES BALANCE IN COASTAL SITES

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An experimental campaign has been performed, measuring the vertical turbulent surface fluxes of heat and water vapour, by the eddy correlation method, joint with the net radiation, in three sites at different distances from the coastline (0.5, 5 and 15 km) in the south-east of Italy.

The aim was to detect the effect of the coastal discontinuity over the vertical fluxes balance when turbulent fluxes are measured at 10 m. height, in terms of correlation between turbulent fluxes and net radiation.

A statistical analysis performed over the obtained fluxes showed that a fairly good correlation holds in two of the sites (5 and 15 km), but it becomes very poor in the third site, probably due to the horizontal advection of heat between the soil and 10 metres height.

The results have been compared with a well-known model of surface flux balance.

MODEL OF THE ENERGY-MASS EXCHANGE IN A COASTAL ZONE.

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Model of the water body - atmosphere exchange is presented. The model allows to calculate the values of the energy-mass exchange in near-the-water atmosphere layer and corresponding interaction characteristics on base of the standard hydrometeorological c aracteristics of the air and water. Data have been obtained from deep water basins, as well as from shallow, at an open sea, as well as in its coastal zone.

Over a shallow sea and coastal zone the increase of wave steepness leads to an increase of waves breakness. Waves breaking increases the intensity of the turbulence exchange processes near the interface.

There has been developed a balance model for calculation of the energy-mass exchange in a coastal zone based on the own experimental data of the basin depth influence on the water-atmosphere interaction intensity.

TURBULENT SIMULATION OF THE AIR FLUX ABOVE INHOMOGENEOUS SURFACES.

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Earlier we (EGS 21, 22) have determined causes of the energy imbalance in the atmosphere boundary layer above inhomogeneous surface. These understandings are being developed here and new relationships for determination of turbulent fluxes, roughness length, bulk transfer coefficients, etc. are propozed. These relationships allow of all turbulence characteristics.

SCIDAR/DOAS MEASUREMENTS DURING THE VOTALP VALLEY EXPERIMENT

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Two optical instruments were developed at the Paul Scherrer Institute. The Scidar (Scintillation detection and ranging) is a scintillometer used to measure crosswind speed and turbulence. The DOAS (Differential Optical Absorption Spectrometer) measures concentration of different trace gases. A combination of Scidar and DOAS was used in the valley experiment of the EU-project VOTALP (Vertical Ozone Transport in the Alps). Four pairs of instruments were set up across the Mesolcina valley (Switzerland) at two different locations and at different heights. One pair of instruments was placed along the valley sidewall to measure inside the slope wind zone. Measurements were made in August 1996 over 3 days during a fair weather episode. The accuracy and reliability of the scintillometer was verified and improved by comparison with aircraft and ground station measurement. The wind data was used together with DOAS measurement to determine fluxes of different atmospheric gases along the valley.

ATMOSPHERIC RADIATION PARAMETERIZATIONS

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In this study hourly measurements of downward flux density of long-wave atmospheric radiation and total solar radiation were used together with simultaneously recorded hourly values of air temperature and relative humidity and observations of cloudiness made during each day, in order to evaluate the most accurate simple predictive models for describing infrared sky flux density under both clear and cloudy sky conditions.. The data were collected in the National Observatory of Athens from 1 January 1991 to 31 October 1991. The results show that a simple linear three-variable model predicting sky temperature from air temperature, vapour pressure and clearness index gives the best results (R=0.969). When two variables are considered, sky temperature seems to be very well estimated by vapour pressure and clearness index (R=0.962). The results are sligthly worse when measured infrared sky flux density in Athens is obtained from estimates of infrared sky radiation under clear skies and conventional cloudiness measurements (R=0.934).

Underestimation of turbulent fluxes and the degree of Inhomogeneity of the land surface around the experimental site

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Methods to determine turbulent fluxes of heat, moisture and momentum in the near-the-surface atmospheric layer by the eddy correlation technique, rely on the Monin-Obukhov similarity theory, which requires stationarity and horizontal homogeneity. Experiments at specially selected sites over land and particularly over sea allowed to develop this concept.
Recent experiments, purposely conducted in non-ideal conditions showed an underestimation of the fluxes. Results from the field experiments FIFE, KUREX, TARTEX, SADE and LINEX, point to a relation between the underestimation of the turbulent fluxes and the terrain inhomogeneity.
To systematise the correction for this effect a scheme is suggested which uses fetch lengths of different surfaces in the environment of the site.
This scheme might be useful for the design of validation experiments in non-homogeneous terrain.

EFFECTS OF SOIL MOISTURE DYNAMICS ON TRANSPIRATION IN A MIXED CONIFEROUS FOREST IN CENTRAL SWEDEN

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The diurnal and spatial variation of water uptake in tree stems due to soil moisture and soil temperature was studied in six different forest stands in the Norunda forest (central Sweden). The Norunda forest differ in tree density, tree age, species composition, soil characteristics etc. and the selected six stands represents some typical as well as some extreme characteristics of the whole forest.
In order to study the water uptake, measurements of transpiration, soil temperature and soil moisture was started during the summer of 1997. Eddy flux measurements of total evapotranspiration has been carried out since 1993.
Transpiration was estimated from direct measurement of sap flow using the Granier radial flowmeter technique in 12 trees in each of the six stands. Soilwater content in the uppermost 20 and 50 cm of the soil where measured with TDR-probes. Soil temperature where measured on 5 and 20 cm depth. Eddy flux measurement where made a 100 m tower using sonic anemometers and infrared gasanalysers. The area covered by the tower measurements is a circle with a radius of 1km from the tower so that all of the six stands is covered by the tower measurements.

SCALING UP OF MEASURED FLUXES FROM A VEGETATION STAND TO THE ECOSYSTEM SCALE: A FOOTPRINT BASED METHODOLOGY

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Flux measurements from meteorological towers over natural vegetation are fraught with many problems associated with the heterogeneity of the surface. This work addresses the difficulty to obtain flux values that are spatially representative at an ecosystem scale, based on measurements over a natural vegetation canopy, such as forest or open savannah. Such vegetation canopies commonly exhibit considerable variability at the stand scale (i.e. patches or groups of trees), that may be several orders of magnitude smaller than the ecosystem scale (the scale of the forest). The difficulty arises from the fact that the flux source area is often comparable in size to the stand scale rather than the ecosystem scale, at which the measurement is aimed. Generic statistical estimates of area-to-area representativeness of flux measurements rely on previous knowledge of the flux variability and its statistics. However, this information is not commonly available. The alternative methodology developed here is based on the possibility of obtaining high spatial resolution data of one or more variables, with coverage over the entire ecosystem, that can serve as surrogates for the flux source strength distribution (e.g. remotely sensed values of NDVI or similar). A footprint model is used to evaluate the weighted average flux surrogate contained in the flux source area. This source area flux surrogate is then compared to the true ecosystem flux surrogate, to obtain a quantitative estimate of the spatial representativeness of the flux source area. With the thesis of a covariation between the representativeness of the surrogate and of the measured flux, a scaled up flux value that is representative for the ecosystem can be evaluated. This method is demonstrated and tested on measured fluxes from Sahelian savannah. First results indicate that this method of scaling up has potential, and should be further pursued.

LOW-LEVEL AIRBORNE FLUX OBSERVATIONS OVER HETEROGENEOUS TERRAIN IN BOREAS

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Eddy-correlation based flux estimates of sensible heat, latent heat and carbon dioxide were obtained by the Canadian Twin Otter research aircraft in 'grid flights' at 30 m over two spatially heterogeneous 16 km x 16 km test sites in North-Central Canada, during BOREAS (boreal ecosystem-atmosphere study) 1994 and 1996. Each of the 31 flights consisted of nine parallel lines, 2 km apart, flown twice in time-centered mode and opposite direction. Flux estimates obtained over overlapping 2 km 'windows' were used to map spatial distributions of fluxes. Composites of several of these maps, obtained under similar flight and surface conditions, represent patterns of surface source and sink distributions that are linked to remote sensing observations of the surface and serve as test patterns for high resolution local climate models. Our analysis discusses the reliability of such composite maps in the light of variability in boundary-layer structure and radiation density. It also addresses the potential effects of internal boundary layer structures associated with changes in surface roughness and temperature on the footprint of airborne observations, and their implications on links between flux observations and remote sensing observations of the surface.

INFLUENCE OF NON-HOMOGENEITY OF UNDERLYING SURFACE ON THE STRUCTURE OF TURBULENCE IN THE ATMOSPHERIC BOUNDARY LAYER

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The present investigation is made based on aircraft measurement of turbulence in the atmospheric boundary layer in the region of Tomsk in the Siberia from the Russian-Japanese co-operative airborne missions of July 1995. The nature of the surface is well-known and described, and there are large areas of it with homogeneous surface characteristics. The turbulence data which were obtained from the lags of the flight patterns at different heights, from 50 to 700 m, were tested using a procedure given by Strunin and Foken (1997), to determine the influence of the underlying surface. The data set was analysed based on the assumptions for turbulence and convection in the boundary layer by Leclarc (1996) and Andreas and Cash (1997), and the blending height concept by Wieringa (1986). From observed structures of the turbulent fluxes, the influence of the blending height on the scaling parameters was not found. The critical horizontal scale as given by Leclarc was also analysed in the data. A direct influence of internal boundary layers on the structure of turbulence could not be found in this case because the lowest flight height was about 50 m. However, due to existence of internal boundary layers, it could be observed that convection did not occur directly above the immediate surface, but on the lee-ward side of the changing surface characteristics. For further investigations of the development of convection and mixing in the atmospheric boundary layer, measurements of fluxes in the upper levels of internal boundary layers (5 - 20 m) are very important.

THE GROWTH OF THE INTERNAL BOUNDARY LAYER IN DIFFERENT STABILITY CONDITIONS

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The vertical structure of the atmospheric boundary layer under stable conditions is particularly sensitive to surface disomogeneities such as roughness changes, slope variations and thermal discontinuities. In this work we address the problem of modelling the internal boundary layer (IBL) growth with special emphasis to stability changes. A linearised spectral model derived from Walmsley et al. (1986) and semi-empirical, local equilibrium models, in the line of Panofsky and Dutton (1984) and van Wick et al. (1990), are critically revisited. The local equilibrium approach is thus extended in order to investigate the effects of stability on the shape of mean wind profiles, the development of the IBL height and to study the relation between upstream and downstream stability in the transition from sea to land and vice-versa. The results are finally applied in order to interpret measurements made during stable atmospheric conditions, in complex terrain, in a typical coastal area of the South of Finland. The resulting model, however, could also be used to predict the IBL height during slightly unstable stratification.

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SPECTRAL ANALYSIS OF TOPOGRAPHIC FORCINGS IN A STABLE BOUNDARY LAYER

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Turbulence measurements have been performed at 3 levels in Antarctica on the Nanceen Ice Sheet, a permanently frozen branch of Ross sea. The measuring station was in the middle of a snowy, horizontally homogeneous area of 25x50 km^2 characterised by a gently slope. This area is surrounded by varying orographic complexities along different directions. In a stably stratified atmosphere these lateral boundary features, as consequence of the interaction of the flow with orography, trigger waves which propagate along the Nanceen Ice Sheet in the shallow layer capped by the temperature inversion. The spectral analysis of wind velocity components and temperature performed by Fast Fourier Transforms shows that orographic complexities and waves significantly perturb the turbulent structure of the stable boundary layer. Their effects are emphasized by the power increment in the mid and low frequency subranges with respect to reference spectra obtained over flat terrain. In the inertial subrange, all generalised spectra display the theoretical dependence on reduced frequency as the scale turbulence rapidly responds to local forcing.

VERTICAL FLUX PROFILES AND PROBLEMS OF ENERGY BALANCE CLOSURE WITHIN THE PLANETARY BOUNDARY LAYER DERIVED FROM EDDY CORRELATION MEASUREMENTS AND TETHERED BALLOON SOUNDINGS

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Near-surface eddy correlation measurements of energy and trace gas fluxes in the complex terrain of the Swiss Seeland region indicate a gap in the closure of the energy balance. It is suggested that mesoscale circulation between the Jura mountains in the northwest and the Prealps in the southeast leads to subsidence over the Seeland region. The advective fluxes driven by this mesoscale circulation are supposed to play a major role in regional transport processes and to fill the gap in the energy balance closure. The surface data are combined with profile measurements from tethered balloon soundings to generate integrated flux profiles for the entire planetary boundary layer. It is aimed to calculate the subsidence rate from vertical flux divergence. Seasonal differences from summer and winter intensive measuring campaigns will be discussed.

SPATIAL AND TEMPORAL VARIABILITY OF SHORT-WAVE RADIATION FLUXES IN AFFORESTED MOUNTAIN REGIONS.

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On the base of long-term field measurements the influence of vegetation and orography on the fluxes of direct solar, diffuse sky radiation and global radiation (both photosynthetically active and integral shortwave) was investigated for mountain regions located on the territory of the former USSR between 43-53 N. These regions are situated in various climatic zones: monsoon, mild zone and extremely continental zone. The results characterize the peculiarities of radiative fluxes in mountain forest regions for different scales of spatial averaging - from altitude belts and macro slopes to the first-order valley slopes and separate ecosystems under the various species content of forests, sun position, atmospheric turbidity and cloudness. The comparison of vegetation effect on radiation fluxes for mountain and plain forests under the close species content and gap fraction condition was made. It was shown that on the level of underlying surface the effect of vegetation on radiative fluxes is comparable or stronger than the influence of relief or cloudness conditions. The estimations of errors for a calculation of radiative fluxes in mountain forest regions without taking into account the influence of vegetation were also shown.

REMARKS ON THE DEFINITION OF FRICTION VELOCITY

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Vertical profiles of fluxes and also of mean variables can, after rescaling of the variables, be described by similarity laws. These relations are universal for a given stability class of the atmosphere. One of the main scaling parameters in similarity theory is friction velocity. Unfortunately, several definitions of friction velocity exist in the literature. Several authors (like the textbook of Sutton, 1953) use the component of the horizontal Reynolds stress vector in direction of the mean wind vector to define friction velocity. Others (see the textbooks of Stull 1988 or Sorbjan 1989) define the friction velocity by means of the absolute value of horizontal stress vector. The two definitions only coincide if the direction of the mean wind vector is parallel to the horizontal Reynolds stress vector. In general, the second definition gives larger values for the friction velocity. In complex terrain the situation is complicated by the fact that the terrain following flow is not necessarily horizontal. Thus, several authors have proposed to use terrain following coordinate systems for the definition of friction velocity. By means of a large dataset of fast SONIC wind measurements the friction velocities resulting from the different definitions are compared. Furthermore, it is shown that friction velocity can be well estimated from horizontal wind speed and even better from horizontal turbulence parameters.

AN EXPERIMENTAL METHOD FOR CHARACTERISATION OF NON-IDEAL MEASURING SITES

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Acoustic travel time tomography, usually used in geophysics and oceanography, is proposed as a method for remote monitoring of the Atmospheric Surface Layer near the ground surface over homogeneous as well as over non-ideal terrain.
Travel time measurements between sources and receivers placed around an array of $260 \times 200\ m^2$ in the known test site Melpitz near Leipzig were carried out to obtain area averaged meteorological quantities. Because of the information content of each measurement about the properties of the atmosphere radiated through a tomographic algorithm can provide a distribution of meteorological parameter values, e.g. area averaged air temperature.
Afterwards, horizontal gradients and a survey of the development of micro-scale structures in the Convective Boundary Layer like thermal bubbles will be derived.
The tomograms lead to statements about inhomogeneities in the underlying surface which may, for instance, result in Internal Boundary Layers and noticeable problems during conventional measuring campaigns.
A combined experiment with an acoustic tomography system and meteorological point measurements was carried out to determine the possibility of upscaling of experimental data conventionally derived and their representativeness for an area in comparison to the tomographic solution.

ESTIMATING TURBULENT FLUXES USING AN OPTIMAL AVERAGING METHOD

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In order to calculate turbulent fluxes using eddy correlation measurements a first task is to determine means and thus fluctuations of meteorological parameters. Assumptions of stationarity (statistics do not vary in time) are widely used in theory of turbulence. However, stationarity should frequently be rejected for instance due to daily cycle of the measured components or changes of weather pattern. The presentation discusses an optimal averaging technique applicable for any "smooth" change in time as compared to measuring frequency. The method is called weighted local regression which represents the optimal linear estimator of an unknown function of time with respect to mean squared error. The function may be the mean or cross-covariance (flux) of turbulence parameters. The averaging time necessary to calculate fluxes may also change in time. The method will be demonstrated by a study on real data available over a grassland and forest.

OA10 Fluxes over terrestrial surfaces

Convener: Jensen, N.O.

02 Long term measurements of surface fluxes

Convener: Valentini, R.

Sponsorship: IGBP-BAHC, EUROFLUX EC Project

LONG TERM MEASUREMENT OF FLUXES IN A MIXED ARDENNES FOREST : 2. IMPACT OF MEASUREMENT ERRORS ON THE ESTIMATION OF THE CARBON SINK MAGNITUDE

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The CO_2 fluxes measured by eddy covariance above a mixed forest at Vielsalm (Belgian Ardennes) in the framework of the EUROFLUX program (see Vandenhaute et al., this issue) were summed in order to estimate the annual carbon sequestration by the ecosystem.
The impact of measurement errors on the estimation of the carbon sink magnitude was analysed. Random, systematic and selective systematic errors were considered separately. The most significant error was the selective systematic error that occurs at night due to the underestimation of the CO_2 flux by the eddy covariance system under low turbulence. We estimated this error by parametrizing the response of night CO_2 flux to temperature on windy nights and replacing the fluxes measured on calm nights by an estimation based on this response. The choice of the selection criterion for windy nights and of the reference temperature at night is discussed. The optimal selection criterion was based on the momentum flux value ($\tau > 0.2$ kg $\cdot m^{-1} s^{-2}$). The trunk temperature was found to be the best indicator. The results show that the selective systematic error may reach up to 40% of the total sequestration.
Acknowledgement: This research is financed by the Belgian Prime Minister's Office – Federal Office for Scientific, Technical and Cultural Affairs and the EU.

MEASURED AND MODELLED CO_2 BALANCES IN A WETLAND ECOSYSTEM IN NORTHERN FINLAND

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The Finnish Meteorological Institute has carried out micrometeorological measurements in subarctic ecosystems in northern Finland as a part of LAPP (Land Arctic Physical Processes), a partially EU funded multinational project in the European Arctic. The measurements on a flark fen at Kaamanen (69°08'N 27°17'E) were conducted from 12 April to the 23 of October 1997. The eddy covariance fluxes of CO_2, H_2O, sensible heat and momentum were measured using an ATI sonic anemometer and a LI-6262 CO_2/H_2O analyzer. The data indicate a short growing season, only extending from mid-June to early September with highest daytime downward fluxes of CO_2 (-0.2 mg $m^{-2}s^{-1}$) at the end of July. The maximum night-time fluxes were about 0.1 mg $m^{-2}s^{-1}$. The corresponding daily CO_2 balances at the end of July were -5 g $m^{-2}d^{-1}$. During the period of snow cover and frozen soil in April, the daily balances were about 0.4 g $m^{-2}d^{-1}$. After the snow thaw and during the autumn months, the efflux was greater, from 1 to 2 g $m^{-2}d^{-1}$. A simple net ecosystem exchance model was adopted for CO_2. This was used to study the processes behind the CO_2 exchange and the daily balances. We used it also to patch the gaps in time series and to estimate the daily balances during the winter time in order to obtain the annual balance. According to preliminary results, the wetland ecosystem at Kaamanen is estimated to be a net source of CO_2 in 1997.

MASS AND ENERGY FLUXES OVER A PINE FOREST CANOPY: ENERGY AND WATER BALANCE CLOSURE, AND INTRA-ANNUAL VARIATIONS IN WATER AND RADIATION USE EFFICIENCIES

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Continuous measurements of momentum and scalar (sensible heat, water vapour and carbon dioxide) fluxes have been performed for about 18 months over a pine forest canopy in the South-West of France, within the Euroflux programme. In a first step the energy balance closure is investigated. Special attention has been given to heat storage in various compartments (soil, litter, biomass and canopy air), evaluated using more than 60 temperature sensors. The results at hourly and daily scale show a reasonably good closure (most often of the order of 90-95 %). At the yearly scale the cumulated daily fluxes show less good an agreement, which can be attributed to an overestimation of nightime net radiation due to condensation on the sensor. Since September 1997 soil water profiles have been continuously recorded. The variations in soil water content agree remarkably well with the balance between precipitation and evaporation. Fluxes of carbon dioxide allow the water and radiation use efficiencies to be evaluated over the whole data set. The intra-annual variations in WUE are shown to be closely related with the air saturation deficit and the intensity of water stress. The relative amount of diffuse radiation turns out to strongly affect the variations in RUE.

CONTROLS ON EVAPORATION IN A BOREAL SPRUCE FOREST

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The surface energy balance over a boreal spruce forest is analyzed using three years of 30-min averaged data. collected during the 1994-1996 BOREAS experiment, 40 km west of Thompson. Manitoba. The residual in the energy balance falls with increasing wind-speed. which may be due to small (10-15%) underestimation of the sensible and latent heat fluxes at low wind-speeds. During spring melt. however. this residual has a high daytime value of 30% of net radiation. Using a Monin-Obukhov formulation and a bulk vegetation model. we calculate vegetative resistance for the boreal spruce forest system. This bulk vegetative resistance decreases with increasing photosynthetic radiation, decreases sharply with relative humidity, and decreases with increasing moss water storage. The temperature dependence shows a broad minimum in the 10-20 F8C range at lower humidities. When the ground is frozen at 10cm. but air temperatures are above freezing. vegetative resistance is roughly doubled.

INTRODUCING CO_2 ASSIMILATION IN ISBA FOR INTERACTIVE VEGETATION

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The ISBA (Interactions between Soil, Biosphere, and Atmosphere) scheme (Noilhan & Planton 1989, Mon. Wea. Rev., 117:536-549) is modified in order to account for the atmospheric carbon dioxide concentration on the stomatal aperture. The physiological stomatal resistance scheme proposed by Jacobs et al. (1996, Agric. For. Meteorol., 80:111-134) is employed to describe photosynthesis and its coupling with stomatal resistance at leaf level (instead of the Jarvis-type parameterization used in the standard version). A representation of the soil water stress effect is obtained by multiplying the mesophyll conductance g_m of the Jacobs' model by the normalized soil moisture in the root-zone. The scaling up from the leaf to the canopy is performed by a 3-point Gauss quadrature integration according to the method proposed by Jacobs et al. (1996) and using the work of Roujean (1996, J. Geophys. Res., 101D5:9523-9532). The computed canopy net assimilation is used to feed a simple growth submodel, and to predict the density of vegetation cover: growth is described as the accumulation of net assimilation, and senescence as the result of a deficit of photosynthesis. The new scheme, called ISBA-Ags, is applied to different micrometeorological databases for which micrometeorological measurements were available over one annual cycle or more: MUREX (Bessemoulin et al. 1996), PILPS/Cabauw (Chen et al. 1997), HAPEX-MOBILHY/Caumont (André et al. 1986), INRA/Avignon (Olioso et al. 1996), INRA/Castanet (Cabelguenne et al. 1990), and ARME (Shuttleworth et al. 1984).

COMPONENTS OF FOREST EVAPOTRANSPIRATION DETERMINED BY MICROMETEOROLOGICAL AND PLANT PHYSIOLOGICAL METHODS

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Forest evapotranspiration over a forest spruce stand is continuously determined 14 meters above the canopy by the eddy covariance energy balance method on a micromet tower. From May to June 1997 additional eddy covariance measurements of latent heat in the trunk space of the trees were made. Evaporation from soil and transpiration from understorey is so independently determined. With these two evapotranspiration measurement levels, over and below the crown, for dry canopy transpiration and for wet canopy the sum of transpiration and interception can be calculated.
Xylem sap flow and stem circumference measurements were made on different trees in the vicinity of the measuring tower. This allows the determination of tree transpiration if active sap wood area is known from additional morphological measurements. Stem circumference measurements show reversible changes. These changes occur, when water transport from the soil in the stem is smaller than water loss through stomata during daytime. During nighttime storage in the stem is refilled from soil water. A correlation between transpiration and changing stem volume is possible. This intermediate storage might explain differences often observed between top-down and botton-up methods for forest transpiration.

Measurements of Soil CO_2 Efflux

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ABSTRACT
In-situ measurement of soil CO_2 efflux has become increasingly common as scientists recognize the utility of these data in such areas as the determination of the carbon budget of terrestrial ecosystems in global change research and evaluation of the impact of pollutant damage to soil organisms and the efficacy of bioremediation efforts. Chamber methods are the most widely used means of measuring soil CO_2 efflux. We present a review of some of the pitfalls to such measurements. We include data from the literature as well as data that we have recently collected to illustrate these pitfalls. We also demonstrate how these pitfalls can be avoided with a carefully designed measurement system.

POTENTIAL AND LIMITATIONS OF USING 12-YEAR SATELLITE DATA OVER GLOBAL LAND

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Data, provided by NOAA AVHRR, contain information on surface characteristics, such as albedo, temperature and state/amount of vegetation. Global time series of monthly anomalies in spectral data at 0.15 deg resolution during last 12 years have been analyzed. The limitations of these time series include residual errors in calibration and satellite orbit drift, which results in changing observational illumination and diurnal cycle effects. Detection of decadal trends on a global scale is discussed. The potential of monitoring strong anomalies, such as El Nino impact on land surface conditions, is demonstrated. Despite its limitations, this dataset is valuable for studying phenology of global biomes and developing a baseline for assessment of surface flux variability for longterm studies using data from future compatible sensors.

COMPARISON OF TRICHLOROACETIC ACID (TCA) CONCENTRATIONS OF TWO SPRUCE SITES IN THE ROSTOCKER HEIDE, NE-GERMANY

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TCA is an ubiquitous anthropogenic secondary air pollutant. It is formed by atmospheric oxidation of volatile chlorinated hydrocarbons (VCH). Consequently the estimation of TCA in conifer needles is a bioindicator method for organic air pollutants as a basis for regionalization in local frameworks. Because of its phytotoxical effects TCA was used as a herbicide in forestry[1] and agriculture up to 1989 in Germany. Levels of TCA in spruce needles from two sites in the Rostocker Heide were compared. The sample sites are at a distance not further than 800m from each other. The spruce stands differ in special ecological features. TCA-concentrations in needles ranged from 3.9 to 23.5 µg/kg fresh weight. TCA levels in older needles were higher than those in younger ones. The levels depended upon season and apparently upon shortterm weather conditions. Spruce needles from sample site I (Sand-Podsol) in all age groups show 1.4-1.6 times significantly higher average concentrations than those from sample site II (Sand-Tiefsalm-Gley). The differences at this short distance could be explained by varied wind and sun exposition and transpiration rate resulting from stock- and canopy density. Other natural factors like ground substrate, organic matter in soil, ground water level or water retention by special strata seem to be causes for promotion or intensification of TCA uptake by the roots.

CO_2 AND WATER VAPOUR FLUXES OVER A DANISH BEECH FOREST

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A long-term monitoring station for fluxes of CO_2 and water vapour was established in the spring of 1996 in a 80-year old beech forest near Soroe in Denmark. The station is one of 15 EUROFLUX stations, sponsored by the EC (ENV4-CT95-0078) and has been in operation since June 1996. A primary goal is to combine flux measurements on a continuous multi-year time basis with ecological processes interpretation and modelling. The forest has an average tree height of 25m and the station consists of a 57-m tower with conventional meteorological profile instrumentation and one level of eddy-flux measurements (a Solent sonic anemometer and a LI-COR 6262 gas analyser). Ancillary measurements such as soil moisture and leaf area index are also done. The paper describes the results until now of the measurements and discuss them in terms of diurnal and seasonal variation in the fluxes. Variations in the fluxes are being investigated in relation to environmental variables.

LONG-TERM MONITORING OF SURFACE FLUXES AT HALLEY RESEARCH STATION, ANTARCTICA

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Halley Research Station (75°S, 26°W) is situated on an expansive and uniform ice shelf and is thus an ideal location for making measurements of surface fluxes that are representative of a wide area. Continuous measurements of surface fluxes have been made at this site since 1995, using both eddy-correlation and profile techniques. We describe the instrumentation used and the problems encountered with making long-term flux measurements in a harsh polar environment. Data from the first two years of measurements will be presented, with particular attention given to water vapour fluxes. Sublimation of surface snow is found to be neglegible during the Antarctic winter, but is a significant loss term in the surface mass balance during summer.

SIX YEARS OF SURFACE ENERGY AND WATER BALANCE MEASUREMENTS AT A SITE WITH AGRICULTURAL LAND USE

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Long-term measurements of surface energy and water fluxes were carried out at a site with varying agricultural land use (wheat, barley, sunflowers, maize and mustard) in the Weiherbach catchment in south-west Germany during the years 1991 to 1996. The sensible heat flux was determined by means of the eddy covariance method, the latent heat flux was calculated from the profiles of humidity and wind speed according to the flux-profile-relationship and as residual of the energy balance, respectively.
During the period of investigations a high variability in annual precipitation occurred which ranges from 500 mm a^{-1} to 1100 mm a^{-1}. It was found that the partitioning of the mean annual available energy into the turbulent fluxes of sensible and latent heat is mainly influenced by the amount of annual rainfall on condition that the precipitation is distributed more or less uniform in time. The variation of the yearly mean values of the available energy was small (about 7%) but showed also a correlation with annual precipitation due to the prevailing synoptic conditions. The influence of different agricultural land use types on annual mean values of the energy fluxes is of minor importance because of their various vegetation periods. In addition the feedback of the turbulent energy fluxes and their ratio on the local climate conditions is presented.

SENSITIVITY OF EDDY CORRELATION FLUXES TO THE METHOD OF FLUX COMPUTATION

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The eddy correlation technique allows direct determination of small-scale fluxes in the atmosphere, subject to numerous assumptions and approximations. The exact method of computing fluxes can vary from experiment to experiment, and indeed should likely be tailored to each specific application. Methods of co-ordinate rotation (for selecting surface-normal fluxes) and effective high-pass filtering (for isolating small-scale motions) are reviewed, and a sensitivity analysis is performed. Fluxes of carbon dioxide, water vapour, and sensible heat are considered using eddy correlation data from two separate mixed forest sites, one over flat ground and one in complex terrain.

EDDY CORRELATION FLUXES OF CARBON DIOXIDE AND WATER VAPOUR ABOVE A MIXED FOREST CANOPY IN THE BELGIAN CAMPINE REGION

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Within the framework of the EC-funded EUROFLUX project, a field experiment was initiated to directly measure atmospheric fluxes of CO2, water vapour (latent heat), and sensible heat above the forest canopy. A sonic anemometer (3-D wind speeds and temperature) and a fast response infrared gas analyser (CO2 and water vapour) are mounted on the tower at a height of 42 m above the forest floor; raw signals are recorded at a frequency of 20.8 Hz. Measurements from these instruments allow calculation of half-hour fluxes via the eddy correlation technique. Supporting micrometeorological measurements are made at various levels within and above the canopy. Half-hour means of net and global radiation, air temperature, CO2 concentration, humidity, and wind speed and direction are logged to provide context for the eddy correlation fluxes. During 1997, nearly continuous measurements were made, with gaps of some weeks due to pump failure (for the gas analyser) and contamination of the infrared laser tube. Uptake of CO2 by the forest during the daytime amounted to ca. 10 mol m-2 s-1 while smaller magnitudes of respiration were observed at night.

A COMPARATIVE APPROACH TO SURFACE FLUXES VARIATION IN THE SOIL/ATMOSPHERE INTERFACE

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Abstract: Studies on the heat and water vapour processes in the atmospheric boundary layer and soil/atmosphere interface are of outmost interest due to its consequences on the problem of water management, atmospheric convection characteristics, probabilities of frost occurrence, etc. So, a description of a micrometeorological experiment for data collection in the atmospheric boundary layer is presented. Analysis of surface water vapour flux, sensible heat flux, latent heat flux and ground heat flux, in different atmospheric stability conditions is achieved. The surface layer fluxes are estimated by eddy correlation method. A comparative approach with other methods is also tried. The effects of atmospheric stability, net radiation and cloud cover on surface fluxes are analysed. Night time fluxes and vertical wind profile are also discussed.

CALIBRATION AND VALIDATION OF THE WATCH-IT MODEL

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A validation and calibration of the WATCH-IT model (P. H. Martin et al., this issue) is performed on measurements of fluxes and of meteorological data made above a mixed forest at the Vielsalm site in the frame of the Euroflux network (Vandenhaute et al., this issue, Aubinet et al., this issue).
Twenty days data set with different meteorological conditions are used for the calibration. The non determined parameters are choosen for the sensitivity analysis (P. H. Martin et al., this issue) and only the most influent one are adjusted by calibration. This adjustement is realized in order to minimize the squared difference between measurements and model estimations of sensible heat, water vapor and CO_2 fluxes above the canopy. The validation is performed on a data set independant of the former. Satisfactory agreement between model predictions and measurements are found.
Application of WATCH-IT allow us to estimate the evolution of fluxes above the canopy and their repartition between the canopy components (air of the canopy, vegetation and soil). We also analyse the importance of the storage of CO_2 in the canopy air and it's feedback on the assimilation.

SCALING OF SCOTS PINE SHOOT PHOTOSYNTHESIS TO CANOPY BY HIGH-RESOLUTION IRRADIANCE MEASUREMENTS

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Simultaneous shoot chamber and eddy covariance measurements were performed for a Scots pine stand (SMEAR II station, Hyytiälä, 61°51'N24°17'E). Shoot scale photosynthesis was scaled to stand level by means of vertical needle biomass distribution, high-resolution irradiance measurements and soil respiration. The PAR distribution from the canopy top (at 13 m) to 8 m was measured by 170 sensors at six height levels with the horizontal range of several meters. The diurnal evolution of the PAR distribution, the correlation between measurement points and the importance of multipoint measurements are discussed together with comparisons of scaled and eddy-covariance determined fluxes.

COMPARING, REFINING, AND STANDARDIZING WATER, CO_2, AND HEAT EXCHANGE MODELING METHODOLOGIES

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The EUROFLUX EC Shared Cost Action is rich in scientific outcomes. In particular, EUROFLUX provides an opportunity to compare, refine, and standardize both measurement techniques and modeling methodologies. This paper focusses on the latter. While canopy exchange models abound, the present modeling exercise is original on at least four different counts: the processes represented in the model, the modeling strategy, the use of the long-term EUROFLUX dataset, and the issues investigated. First, the WATCH-IT (WATer, Carbon dioxide, and Heat Integrated Transfer) scheme intimately couples stomatal behaviour, momentum, heat, and water exchange, and CO_2 assimilation. Second, to the usual "design/programming/testing/calibration/validation" sequence, an exhaustive sensitivity analysis was added. The sensitivity analysis challenged our understanding, revealed possible problems, and highlighted candidate tuning parameters. Third, the long-term EUROFLUX dataset was used extensively for calibration and validation. Fourth, and finally, the implications of including CO_2 storage in the canopy were investigated.

MONITORING OF LONGWAVE RADIATION IN THE SWISS ALPS

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Long term measurements of longwave radiation are an important contribution to the dedection of an increasing greenhouse effect. For the study of the Alpine Surface Radiation Budget (ASRB) a new automatic radiation network has been established. A total of eleven stations at elevations between 400 and 3600m a.s.l. are measuring short- and longwave radiation with high resolution and accuracy. The standard instrumenation consists of a Kipp&Zonen CM21 Pyranometer for shortwave radiation and an Eppley PIR Pyrgeometer for longwave radiation fluxes. A Travelling Standard guarantees for the stablility of the measurements. Data of the first two years are used to show the yearly cycle of longwave downwelling radiation on different elevations.

DRY DEPOSITION FLUXES OF TRACE GASES AND THEIR SEASONAL VARIATION BASED ON CONTINUOUS MEASUREMENTS OVER A PINE FOREST

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Continuous measurements of turbulent fluxes of ozone and sulphur dioxide over a homogeneous forest area have started in January, 1996. Meteorological parameters and gas concentrations are measured in and above a Norway Spruce forest using five minute averaging time. Gradient technique are used to calculate the dry deposition fluxes and deposition velocities of these trace gases. Different resitance values of the near surface layer and the canopy are also calculated from measured meteorological data and surface characteristics. Daily and seasonal variation of these resistances, deposition velocities, and turbulent fluxes of ozone and sulphur-dioxide are presented in this study.

ATMOSPHERIC FLUXES OF CO_2 ABOVE A HIGH ARCTIC FEN FROM SPRING TO AUTUMN TWO SUCCESSIVE YEARS IN NE-GREENLAND

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Turbulent fluxes of CO_2 were measured by eddy correlation continuously for two months in 1996 and 3 months in 1997 over a wet fen system at Zackenberg (74 28'N,20 34'W) in NE-Greenland. The 1996 season can be regarded as relatively dry and warm compared to 1997, where the snow melt and thus the set in of the growing period occurred 14 days later than in 1996. The 1996 measurements started just after snow melt late June and continued until the end of the growing season in the middle of August. The 1997 measurements started on a 1-1,5m cover of dry snow 1 June and was closed down in the end of August which correspond to late autumn at this high arctic site. The fens consist of grasses and sedges and have water levels over, at or just beneath the soil surface. All of a spring emission "flush" of CO_2 was observed during snow melt in the 1997 data reaching values on 0.2 $mgm^{-2}s^{-1}$ or almost 9 $gm^{-2}day^{-1}$ CO_2. Uptake increased over the period and attained values up to 0.4 $mgm^{-2}s^{-1}$ or 12 $gm^{-2}day^{-1}$ CO_2 in the middle of the growing season. The fluxes displayed a clear diurnal variation during the entire period primary controlled by incident solar radiation. A curvilinear relationship between absorbed PAR and CO_2 flux was found. In 1997 the period with daily emssion loss, before the system shifted to daily net-uptake, amounted to 101 gm^{-2} CO_2. The period with daily net-uptake totalled 231 gm^{-2} and the total net-ecosystem balance for all of the 1997 season, displayed thus a net-sink on 130 gm^{-2} CO_2.

MEASUREMENTS OF CO_2, CH_4, SENSIBLE AND LATENT HEAT EXCHANGE AT DIFFERENT TUNDRA SURFACES IN A HIGH ARCTIC ENVIRONMENT

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Results from a concentrated effort to measure mass and energy fluxes by eddy correlation over different surface types at a locality in the high arctic region are presented. The measurements took place at Zackenberg (74°28'N,20°34'W) in NE-Greenland 1997 from 1 June to 26 August, which on this location correspond to a period from spring to autumn. Eddy correlation setup's were established representing fluxes from: 1) a wet surface with grassy vegetation 2) a heath land vegetation. Additionally a tall mast was erected to measured fluxes representing an intergrated contribution from a mixture of different surfaces included the two abowe mentioned. CH_4 fluxes were only measured at the wet site. Clear diurnal and seasonal variations were seen at the three sites. In the case of net-ecosystem CO_2 exchange, fluxes over the wet surface with dense grass vegetation. were about 4 times as large as the CO_2 fluxes from the heath land. The CO_2 fluxes measured from the tall mast attained values in between. CH_4 fluxes measured by eddy correlation with the use of a tunable diode laser, culminated at the same time as the maximum CO_2 uptake, reached values of about 120 mgm^{-2} day^{-1} and decreased thereafter gradually.

Absolute Measurements of Night Sky Downwelling Longwave Radiation

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Long term monitoring of downwelling longwave radiation at different altitudes allows to trace effects and possible trends due to increased greenhouse gases in the atmosphere. New blackbody calibration techniques together with improved dome temperature measurements on pyrgeometers provide high relative precision of better than 3 Wm-2 between different instruments. However, large differences between the spectral distribution of thermal atmospheric radiation and Planck radiation sources prevent an absolute calibration of pyrgeometers with blackbody radiation sources. A windowless pyroelectric radiometer is therefore used to measure downwelling longwave radiation of a clear night sky with absolute accuracy. Sky radiance measurements at a solid angle of six degree are made at four selected zenith angles in four azimuthal directions. Gaussian integration is used to determine the hemispherical downwelling longwave irradiance on a horizontal surface. This instrumentation provides a method for absolute calibration of pyrgeometers during perfect clear night sky.

A statistical study of NDVI sensitivity to seasonal and interannual rainfall variation in Southern Africa.

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NOAA satellites carry out long term measurements of surface conditions, as the Normalized Difference Vegetation Index (NDVI). Rainfall-photosynthetic activity relationship is investigate at relative large scale (continental and interannual) using these data. For Southern Africa south of 15 S, the aim is to better understand the spatial characteristics of NDVI sensitivity to seasonal and interannual rainfall variability, using an original rainfall dataset. Over the 1983-1988 period, with monthly values on 1 *1 grid point dataset, the study will show the influence of geographical conditions as soil and vegetation types on seasonal an interannual rainfall-NDVI relationship.

MONTHLY VARIABILITY OF ENERGY AND MATTER FLUXES OVER AGRICULTURAL CANOPIES. THE INFLUENCE OS MESOSCALE AND MICROSCALE PROCESSES.

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To analyze the spatial and temporal variability of energy and matter superficial fluxes above an irrigated and dry agricultural areas, and the factors that controls the transport rate, we carried out continuous long term measured and calculated fluxes. Based on ten minutes averaging measurements we have characterized and compared for each month, the diurnal evolution of net radiation, soil heat flux, latent heat flux and sensible heat flux. In all period the values of the two last fluxes are calculated by Bowen ratio energy and similarity theory of Monin-Obukhov, whereas, for a short period, sensible heat flux are measured by eddy correlation system, the three methods have been compared. Simultaneously, this long term measurement allowed us to examine in both measurements stations, since there are located in quite different places, the influence of the mesoscale and microscale factors like the orography, the dominant winds, (winds rose), the soil humidity and soil cover respectively.

A SIMPLIFIED AERODYNAMIC METHOD TO MEASURE AMMONIA FLUX OVER FIELD CROPS UNDER MEDITERRANEAN CLIMATE

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Ammonia (NH_3) is a chemically highly active gas in the atmosphere and has great impact on air pollution. Many methods have been developed in the last years to evaluate emissions/depositions of NH_3 from/to terrestrial surface. The direct methods (chambers, chemical traps) measure NH_3 only in a limited number of points, so that the measurements are difficult to generalize. Micrometeorological methods, mainly based on flux-gradient relationships are the best, but often are difficult to set up because they require measurements at three (or more) levels above the surface. In this work a simplified aerodynamic method (SAM) to estimate flux was tested; The trial was carried out in an agricultural area of Southern Italy near the Tirrenic coast. NH_3 concentration was measured at two levels above a Lolium crop, fertilized with $CaNO_3$. Measurement were performed over a 2 hours sampling period by trapping air NH_3 in a H_2SO_3 solution and analysing the sample in the laboratory with the colorimetric method, using Nessler solution. SAM fluxes were compared to those computed by the complete aerodynamic method (concentrations measured at three levels above the crop). The test showed that SAM correctly estimate NH_3 emissions/depositions during the day. Some problem arises during the night, in particular when the flux is toward the surface (deposition).

DETERMINATION OF TURBULENT FLUXES OF CARBON DIOXIDE AND WATER VAPOUR IN DIFFERENT MEASURING HEIGHTS ABOVE SPRUCE FOREST IN SOUTH-EAST GERMANY

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Turbulent fluxes of carbon dioxide, water vapour and sensible heat were measured in two heights above a young spruce forest (*Picea abies*) in the frame of the EUROFLUX-project by means of the eddy covariance method since June 1996, working in parallel since May 1997. The site is located in mountainous, inhomogeneous terrain (Lehstenbach / Fichtelgebirge) in south-east Germany.
Differences in the net carbon exchange of the ecosystem as well as in evapotranspiration and sensible heat flux are found between the two systems. All absolute values of the carbon dioxide and energy exchange rates are usually higher in the upper measuring height leading to a better energy balance closure compared to the lower one. This results also in significant differences in the carbon balance of the forest especially during the vegetation period. It is discussed where the differences arise from and which method can be used to determine the CO_2-exchange on such non-ideal conditions. Footprint analysis imply that the measurements in the upper height do not always represent the fluxes from the patch of the younger forest surrounded by older and higher trees. As a consequence a combination of the data from both heights depending on the atmospheric stability is used to determine the local net carbon ecosystem exchange.

CO_2 EXCHANGE IN MIXED HARDWOOD FORESTS IN THE MIDWESTERN UNITED STATES: TWO AMERIFLUX PROJECTS

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The two AmeriFlux projects presented here are very similar in their objectives: to obtain long term eddy-flux measurements of CO_2 exchange with the forest. However, due to distinct differences in their regional setting, the methods to achieve them and the challenges involved are different. One site is located in Morgan-Monroe State Forest, Indiana (MMSF, 39° 10' N 86° 25' W, mixed hardwoods, ~25 m canopy height). The 45 m flux tower has a minimal forest-fetch in principal wind direction of ~ 4 km. This area is characterized by small scale ridge/ravine topography, resulting in differences of moisture availability over short distances. The second site (northern mixed hardwood forest) is operated by the University of Michigan Biological Station (UMBS, 45° 34' N, 84° 43' W) in northern Michigan. In the main wind direction, topography is very slight for several km. However, the observation tower site is located 1 km away from Douglas Lake (~ 5 x 6 km). The objectives of both sites center on obtaining regionally representative, continuous long-term flux observations of atmosphere-forest CO_2 exchange. Fluxes are measured by eddy correlation at several heights above and below canopy, to ensure multiple flux footprints at all times. At the MMSF site the challenge posed by the inhomogeneity of the surface is to incorporate a representative composite of small-scale patches to form a valid average. In contrast, at the UMBS site, the challenge is to separate the flux contributions from the forest and from the lake, to obtain fluxes that are representative for the forest ecosystem. The objectives and methods at these two sites will be discussed in more detail and will be illustrated by first results.

AMERIFLUX – THE CARBON FLUX NETWORK OF THE AMERICAS: AN OVERVIEW OF OBJECTIVES AND GOALS

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Significant net uptake of CO_2 by terrestrial ecosystems has been postulated to account for the so-called "missing carbon sink" of the global carbon budget. The rate of accumulation of CO_2 in the atmosphere, and the net primary production of terrestrial ecosystems vary enormously on interannual and decadal time scales. We are currently unable to account definitely for these observations, and these gaps in understanding the global carbon cycle cause significant uncertainty in predictions of future concentrations of atmospheric CO_2. The goals of the AmeriFlux network are to address this concern by (i) contributing new information to help define the current carbon budget, based on long term measurements of net flux of CO_2 to/from major terrestrial ecosystems, (ii) enabling improved predictions of future concentrations of atmospheric CO_2 based on enhanced understanding of responses of net primary production to changes in climate, and (iii) enhancing understanding and advice on the consequences of potential CO_2 mitigation policies. AmeriFlux has similar objectives to other carbon flux networks (e.g. EUROFLUX), but exhibits some differences in approach and organization. The role of AmeriFlux is to coordinate the presently 29 flux sites, each with their own funding sources, time scales and observational approaches. The aim is to cover all important terrestrial biomes, including (presently) different types of deciduous and coniferous forests, grasslands, arctic tundra, semi-arid chaparral, alpine and sub-alpine sites, boreal forest, and tropical wet forest. Data products will be cross-calibrated routinely and made available in a comprehensive database. Further information on AmeriFlux's science plan can be found on the internet at **http://www.esd.ornl.gov/programs/NIGEC**.

LONG TERM STUDY OF WET AND DRY DEPOSITION OF SULPHUR AT A RURAL SITE IN EASTERN GERMANY

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In 1992 the research station Melpitz (meadow, 86 m a.s.l.) about 40 km northeast of Leipzig has been established to observe the rehabilitation of the atmosphere above the new federal states of Germany after the reunification in 1990. The dry deposition of SO_2 was estimated by using a continuously running profile system. The wet deposition of sulphate was determined by means of the precipitation volume (wet only sampler) and the concentration of sulphate in rain water. The total sulphur deposition was calculated from the sum of the wet and dry deposition. In this five year period the concentration of sulphur in precipitation decreased about 40% and the wet deposition about 30%. The decrease in SO_2 concentration was about 70%, while the dry deposition showed no continuous decrease. This may be due to the varying deposition velocity from 0.1 cm s^{-1} to 0.4 cm $s^{-1}$and the variation of the canopy resistance of SO_2. Some information is given about the ratio of dry deposition of sulphate in aerosols and about the behaviour of ozone dry deposition during the five year time period. The variability in the ratio of wet to dry sulphur deposition is shown.

OZONE DEPOSITION TO A SCOTS PINE AND A MOUNTAIN BIRCH FOREST IN NORTHERN EUROPE

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Results are presented from two extended micrometeorological campaigns including measurements of ozone deposition and related turbulent fluxes above two forest ecosystems in Finland: (1) a Scots pine forest in the southern boreal zone (62°52'N, 30°55'E), 9 June to 4 Aug. 1995; and (2) a subarctic mountain birch forest in the northern boreal zone (69°28'N, 27°14'E), 29 May to 16 Sept. 1996. The measurements were performed by using the eddy covariance technique. The fluxes are interpreted in terms of a big-leaf resistance model, and common parametrisations of the surface resistance are tested. For the pine forest, a comparison with the Wesely scheme showed a good agreement for the mean diurnal cycle of the deposition velocity, and during midday, also for the mean surface resistance. To improve the fit during night, the resistance of external surfaces had to be reduced. The mountain birch data indicates a strong seasonal variability, demonstrating the shortness of the growing season in the north. Once the leaves emerged, relatively high deposition velocities with only a moderate diurnal cycle were observed.

LONG TERM MEASUREMENT OF FLUXES IN A MIXED ARDENNES FOREST : 1. INFERENCE OF FUNCTIONAL RELATIONSHIPS

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In the framework of the EU-funded networks ECOCRAFT and EUROFLUX, continuous measurements of fluxes were made for a year at Vielsalm, in the Belgian Ardennes. The site is a mixed forest with deciduous and coniferous stands. Fluxes of momentum, sensible heat, water vapour and CO2 were measured continuously on a half hour basis using the eddy covariance method. Temperature, humidity, radiation, precipitation and leaf area index were also measured.
The measurements were used to infer the physiological response of the ecosystem fluxes to climate and other environmental variables.
Night-time measurements gave whole system respiration as a function of bole temperature. This function was then used to estimate the gross primary productivity (GPP). The GPP response to radiation was analysed. The light-saturated GPP and the quantum yield efficiency were deduced from regression for each month. The seasonal evolution as well as the dependence on phenology, water availability and canopy conductance were investigated. There were significant differences between deciduous and coniferous stands in spring and autumn, but differences were negligible during the growing period. A sensitivity analysis of the parameters to the regression type was also performed.
Acknowledgement: This research is financed by the Belgian Prime Minister's Office – Federal Office for Scientific, Technical and Cultural Affairs and the EU.

SOIL RESPIRATION IN COLD CLIMATE FOR A SCOTS PINE STAND

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Winter-time eddy covariance measurements (at SMEAR II station, Hyytiälä, 61°51'N24°17'E) have revealed a significant source of CO_2 from the soil through the snow pack. Simultaneous shoot cuvette measurements allow the subtraction of canopy respiration and the results are compared with observations obtained from soil chambers. In addition, the CO_2 source term within the soil and microbial activity are determined by sampling. We discuss the importance of soil temperature and the depths of permafrost and snow cover as controllers of respiration.

OA11 Mesoscale transport of air pollution, including land/sea areas

Convener: Artinano, B.
Co-Convener: Mikkelsen, T.

VARIATIONS OF RADIATIVE FLUXES IN ARM-EXPERIMENT IN CONNECTION WITH CLOUDINESS (MEASUREMENT AND MODELLING)

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On the basis of the experimental data, obtained at the experimental polygon (Oklahoma State, USA) in the Atmospheric Radiation Measuring Programme, the statistical analysis of the radiation fluxes, temperature, humidity, cloud op i cal thickness and amount for the different cloudiness levels were conducted. Dependence of the surface net radiation balance on the incoming solar fluxes was formed for various cloud types. Experimental results by radiation variability were compared with the calculations, per o rmed in ARM-programme, and with our own numerical estimations.

THE MONCHEGORSK ARCTIC MESOSCALE EXPERIMENT: MEASUREMENT AND MODELING OF ATMOSPHERIC POLLUTION OVER A COMPLEX TERRAIN

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The program of the international Monchegorsk experiment on investigation of processes of local atmospheric transport of industrial pollution over a complex terrain in the Arctic latitudes is described. The study object is the Monchegorsk district on the Kola Peninsula in northwestern Russia. This is a region with a very unfavourable ecological situation due to pollution from the 'Severonickel' smelter. The experiment was carried out during summers of 1993-1994, and included:
- Measurement of meteorological elements at 9 sites and 3 meteorological stations;
- Balloon radio-sounding: registration of pressure, wind velocity, air temperature, humidity, SO_2 and O_3 concentration at different elevations;
- Measurements of surface air concentrations of SO_2 and O_3 by different methods;
- Measurement of SO_2, NO_x and O_3 using a mobile laboratory;
- Investigation of fractional composition of heavy metal particles in the surface layer.

To choose the measurement sites in the region, a mathematical modelling of meteorological fields and transport of pollutants was implemented for the experiment conditions with varying input parameters. Data, obtained during the experiment, is used for verification and development of numerical meso-scale models of the atmospheric dynamics and pollution transport over a complex terrain.

TESTING METEOROLOGICAL FIELDS AND PBL PARAMETERIZATIONS FOR MODELLING TRANSPORT, DISPERSION, AND DEPOSITION - VALIDATION AGAINST ETEX-1, ETEX-2, AND CHERNOBYL

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A tracer model for studying transport, dispersion, and deposition of air pollution caused by a single but very strong source has been developed. The model is based on a combination of a Lagrangian short-scale puff model and an Eulerian long-range transport model. The Lagrangian model is used in the area near the source to calculate the initial transport and dispersion of the release and the Eulerian model is used for long-range transport calculations in the whole model domain. The meteorological meso-scale model MM5V1 is used as a driver for the transport model. Different meteorological input fields and different comprehensive and simple parameterizations of mixing height, dispersion, dry and wet deposition have been included in the model and compared by using numerous statistical tests. The model has been run and validated against the two ETEX releases and the Chernobyl accident. 2-D and 3-D visualization techniques are important tools for the development of the model, for validation of the model results and for a better understanding of the different processes studied by the model. Such visualizations together with comparisons with measurements will be presented and discussed.

EFFECTIVE MODELLING OF THE LOW TROPOSPHERIC FLOWS AND ADVECTIVE-DIFFUSIVE PROCESSES WITH A SINGULAR INITIAL CONDITIONS

Remigiusz Brojewski, AVIOMET Ltd
E-mail: **Fehler! Textmarke nicht definiert.**

Work presents problems connected to modelling and stability of air flows in the lower troposphere. In the anelastic model of a two-dimensional flow with surface and volume sources of vorticity three different regimes of solution: stationary, oscillatory and chaotic were observed. A stream function for wind is used. Applying the method of perturbations to the three-dimensional model based on primitive equations for an incompressible flow in a stationary regime, the possibility of the reconstruction of the vertical profile of the flow velocity is demonstrated. The topography dependent orographic drag coefficient was introduced. To get more efficient computational schemes for advective-diffusive processes with singular initial condition different stages of decomposition method for 3-D model of a transfer of the matter with such processes as a diffusion, sources and sinks were tested. As a result, after applying the correction of a dispersion and a group velocity, normally deformed by classical schemes, the efficient numerical schemes were obtained.

PERFORMANCES OF THE DISPERSION CODE SAFE_AIR USING DIFFERENT PROCEDURES TO CALCULATE THE ADVECTIVE WIND

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The SAFE_AIR code simulates the transport and diffusion of airborne pollutants using Gaussian plume segments and/or puffs. The code is able to deal with both nonstationary and nonhomogeneous situations. SAFE_AIR is an evolution of the AVACTA II code, a code "recommended" by the U.S. EPA. With respect to the AVACTA II code, SAFE_AIR contains a few improvements among which the change of the wind field generation procedure and different algorithms calculating the wind field spatial average providing the advection velocities of the pollutant elements (these algorithms differ among one another because of the number of cells involved in the averaging procedure and the relative weight given to cells).
The evaluation of the performances of the code using the cited algorithms has been performed using laboratory data from the EPA wind tunnel Rushil experiments (two-dimensional schematic hill, neutral conditions). This work also contains the results obtained using the different algorithms when the code is applied to a real situations above a very complex orography (Liguria Region, Italy).

A MESOSCALE STUDY OF A DESERT PLUME OVER WEST AFRICA AND EASTERN ATLANTIC. PART 2 : DYNAMICAL AND MICROPHYSICAL FEATURES.

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The Saharan dust haze is generated by wind erosion of the unprotected arid surfaces of the Saharan desert and its borders. About 1 GT of Saharan dust is mobilized each year in this way. Then dust is transported over large distances, as far as America and Europe. At last it settles by gravitation (dry deposit) or is scavenged by rain (wet deposit).
The spatial extension and the high frequency of occurrence of dust plumes is such that they have a significant effect on the global climate through their direct impact on the radiative budget of the Earth-atmosphere system.
The simulation of mobilization, transport and deposition of dust, and of its radiative impact is currently in progress. The model used is the CSU RAMS for the mesoscale transport, in association with a new physical dust emission scheme, a dry deposition module, and a radiative code.
The purpose of this paper is to present results of a dust event generated by a Saharan source and transported towards the Atlantic ocean, with special emphasis on the dynamics of the plume trajectory and the microphysical evolution. Validations are made through remote sensing data and by dust sampling at ground.

THE INFLUENCE OF SUBGRID SCALE MIXING ON THE TRACE GAS DISTRIBUTION IN A NUMERICAL WEATHER PREDICTION MODEL

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The concentration distribution of trace gases is influenced by cumulus convection. Numerical weather prediction models resolve only scales much larger than the cumulus scale. Therefore the effects of convective clouds on the atmospheric variables and on the trace gas concentrations have to be parameterized. We included an equation for the transport and diffusion of trace gases in the numerical weather prediction model of the German weather service (DM-model). The numerical grid, the integration procedure and the parameterization schemes are identical to those used for the atmospheric variables. The whole model system runs in a coupled mode. For the treatment of the convective scale processes the Tiedke scheme (Tiedtke, 1989) is used in which the subgrid scale processes are parameterized separately for cumulus updrafts and cumulus downdrafts. Simulations performed for July 29, 1996 prescribing an initial concentration of ozone show that the process of cloud venting produces a change of about 20% in the concentration distribution after 12 hours.

A MESOSCALE STUDY OF A DESERT PLUME OVER WEST AFRICA AND EASTERN ATLANTIC. PART 1 : RADIATIVE IMPACT.

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The Saharan dust haze is generated by wind erosion of the unprotected arid surfaces of the Saharan desert and its borders. About 1 GT of Saharan dust is mobilized each year in this way. Then dust is transported over large distances, as far as America and Europe. At last it settles by gravitation (dry deposit) or is scavenged by rain (wet deposit).
The spatial extension and the high frequency of occurrence of dust plumes is such that they have a significant effect on the global climate through their direct impact on the radiative budget of the Earth-atmosphere system.
The simulation of mobilization, transport and deposition of dust, and of its radiative impact is currently in progress. The model used is the CSU RAMS for the mesoscale transport, in association with a new physical dust emission scheme, a dry deposition module, and a radiative code.
The purpose of this paper is to present results of a dust event generated by a Saharan source and transported towards the Atlantic ocean, with special emphasis on the radiative impact. Validations are made through remote sensing data acquired from the ground (photometry) and from space (satellite data).

X-RAY FLUORESCENCE ELEMENTAL ANALYSIS OF TSP AT CASTELLON, SPAIN

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Atmospheric aerosol samples were collected near the coast at Castell¾n (a Mediterranean Spanish city). During a period of six months between February and August of 1992 a daily sample was collected by means a High-volume sampler using Whatman GF/A fibre filters as collection media. Elemental chemical analysis of samples obtained were performed by a Siemens S-3000 X-ray fluorescence spectrometer (SEM/EDX), using SRM -1648 (urban particulate matter) as reference material for test the analytical method used. Significant amounts of Na, Mg, Al, Si, S, Cl, K, Ca, V, Cr, Mn, Fe, Zn, Ba and Pb were found. Ambient concentrations for TSP and each element were calculated. Statistical correlation between several elements, time temporal series showing a seven order correlation and a predominance of natural origin were find. Authors are grateful to the Fundaci¾ Caixa Castell¾ for financial support throws the 61383 project.

CALCULATION OF METEOROLOGICAL DATA WITH ATMOSPHERIC MODELS OF DIFFERENT HORIZONTAL RESOLUTION

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Atmospheric data derived from measurements or calculated by routine weather forecast models are mostly given in a horizontal resolution of some 10 km. These data generally do not include mesoscale-γ atmospheric phenomena caused, for example, by temperature differences between the land and sea surfaces or by tidal influences. However, the mentioned atmospheric phenomena can be incorporated in the data by calculating them with high-resolution atmospheric models.

In this contribution simulation results of the mesoscale transport and fluid model METRAS are presented for the second measuring period of the KUSTOS-experiment, which took place in the area of the German Bight in April and May 1995. The model results are compared with corresponding data of the Deutschland model as well as with routine measurements of the German Weather Service. The model results and the measurements are compared aud discussed with respect to the wind, the temperature, and the specific humidity.

REMOTELY SENSED SURFACE SENSIBLE HEAT FLUX FOR AIR POLLUTION DISPERSION STUDIES

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Modelling studies of urban to regional scale air pollution dispersion often encounter the obstacle of having to specify surface sensible heat fluxes and atmospheric stability. Since those parameters are not routinely available from meteorological networks, a method was developed to infer their spatial distribution from satellite remote sensing. After a description of the method, its feasibility is demonstrated and its validity is assessed by comparing satellite-retrieved sensible heat fluxes with experimental data. Furthermore, directions are given for the method's extension towards an operational processing scheme.

TRACKING THE DYNAMICS OF AN ELEVATED PLUME ON THE SPANISH LEVANTINE COAST.

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Since 1994, a vigilance program of the plume dispersion from the Andorra thermal power plant has been maintained, by systematically following its SO_2 emissions with a mobile unit instrumented with a COSPEC system (correlation spectrometer) and a fast response conventional SO_2 ground monitor. The power plant is located in the SE of Spain, placed on the plateau border of the Ebro Valley, at about 120 Km from the coast, with a 300m high stack and 1200 MW of total power. The plume evolves within a diverse and complex atmospheric dynamics, that changes in accordance with the dominant meteorological conditions and their interaction with the surrounding topography. Some of the typical dispersion patterns from the elevated emissions in the region have been identified. Under intense advective conditions, the emissions get trapped in the general flow, showing a tendency to be channeled along the Ebro Valley axis. The mechanical turbulence generated by the mountain ranges produces impacts on the ground, although these are minor and concentrated at the tops and higher parts of the mountains. Under convective conditions, especially in summer, high levels of SO_2 concentrations can be measured near the ground, and it is especially under such conditions that secondary valleys play an important role in the dispersion of pollutants, as they act as mesoscale circulation generators (hillside and valley breeze types).

AGEOSTROPHIC CIRCULATIONS OVER THE AZORES OCEANIC FRONT DURING THE SEMAPHORE EXPERIMENT

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During the anticyclonic synoptic situations of the **SEMAPHORE** experiment (1993), it has been observed an increase of the wind intensity in the Marine Atmospheric Boundary Layer (MABL) from the cold to the warm side of the Sea Surface Temperat-ure (SST) front linked to the Azores current.
The fundamental point is the ageostrophic character of this acceleration, therefore the strategy used was to establish the primitive equations for the ageostrophic motion in order to analyse its forcing terms. These equations are deduced from the conservation of the thermal wind balance which were initialy established by Sawyer-Eliassen (SE) (1963) in the 2D and quasi-geostrophic cases. The generalized SE equations (primitive form) allow to establish an extension of the Hoskins (1978) form of the vertical velocity which have five forcing terms : two thermal and three dynamic forcing terms. Forcing terms were computed in the non-hydrostatic model Meso-NH of the CNRM and LA laboratories, for the 3D simulation of the 12 November 1993. The results show that the dynamic forcings are the same intensities than the thermal forcings, that put highlights the complexity of the MABL structure. On the other hand, this approach allowed to show the strong coupling between the flow and the turbulent heat fluxes in the first 200 meters above the surface. This layer can be assimilated to an internal boundary layer for the dynamic.

X-RAY DIFFRACTION PHASE IDENTIFICATION OF THE ATMOSPHERIC AEROSOL NEAR THE MEDITERRANEAN COAST

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Atmospheric aerosol samples were collected near the coast at Castell¾n (a Mediterranean Spanish city). During a period of six months between February and August of 1992, a daily sample was collected by means a High-volume sampler using Whatman GF/A fibre filters as collection media. Samples obtained were studied by X-ray powder diffraction, using an X-ray powder diffractometer Siemens D-5000. Major and minor phase identification was performed using complete JCPDS database. Quartz, calcite, halite, gypsum, illite, vermiculite and other minor phases were identified. Time temporal series showing a seven order correlation and a predominance of natural origin were find. Authors are grateful to the Fundaci¾ Caixa Castell¾ for financial support throws the 61383 project.

TEST OF MATHEMATICAL SOLVERS FOR CHEMICAL MECHANISMS IN 3D-AIR QUALITY MODELS

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Air quality simulations combining the solution of both a system of partial differential equations for the corresponding meteorological variables and a system of ordinary differential equations (ODE) for the concentration of chemical species. In literature one can find numerous studies on the accuracy and on the numerical efficiency of solution algorithms (solver) for ODE's. These numerical studies are exclusively performed in zero-dimensional (box) models taking into account variations of chemical sources/sinks for photolysis rates, emissions, deposition velocities, etc. Other processes are not considered which may have also an considerable influence on the stiffness of the ODE and, therefore, on the accuracy of the solution using a certain solver. To the later group of processes belong e.g. the three-dimensional advection and turbulent transport.
The 3D- , non-hydrostatic air quality model METRAS is employed to study the effect of different solvers on the concentration development during the TRACT campaign taking into account the whole range of effects on species concentrations in the model. Comparisons will be shown and results will be discussed in the context of multi-dimensional air quality simulations.

DETERMINATION OF SOURCE ORIGIN OF ATMOSPHERIC TOTAL SUSPENDED PARTICLES AND PM10 PEAKS IN A RURAL AREA FROM THE WESTERN MEDITERRANEAN BASIN

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This study focuses on the identification of major particulate sources and the determination of the time variability of TSP and PM10 levels. It was performed in a rural area from NE Spain affected by a large coal-fired power plant emissions in order to evaluate the relevance of the natural and anthropogenic sources as well as the local or external inputs.The results show a marked seasonal trend, which is characterized by particulate levels that were higher in spring-summer and decreased progressively towards winter. The external particulate inputs affecting this area of the Mediterranean basin (mainly Sahara air mass intrusions) account for major particulate peaks recorded at the monitoring stations. The influence of the emissions from the power plant in the PM10 and TSP levels is evidenced only in periods with a low background particulate levels.

QUANTITATIVE X-RAY DIFFRACTION ANALYSIS AND SIZE DISTRIBUTION OF AIRBORNE PARTICULATE

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Atmospheric aerosol samples were collected near the coast at Castell¾n (a Mediterranean Spanish city), during a period of seven months between April and December of 1992 using a High-volume sampler equipped with a five stages cascade impactor without filters. Samples obtained were studied by X-ray powder diffraction, using an X-ray powder diffractometer furnished with a G÷bel mirror. For each stage, major and minor phase identification were performed using JCPDS data base and quantitative analyses were performed by the Rietveld, Rius and reference intensity ratio (RIR) methods. As major phases, quartz, calcite, halite and gypsum were identified and quantified their amounts and their distribution versus particle size. Authors are grateful to the Fundaci¾ Caixa Castell¾ for financial support throws the 6I383 project.

MODELLING OF SO_2-TRANSPORT OVER HIGHLY COMPLEX TERRAIN WITH METRAS

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Although SO_2-pollution has been reduced considerably in the eastern parts of Europe in the last couple of years, recent measurements show that it can still be an issue in the *Erzgebirge* in southern Saxony in Germany. In particular when high pressure systems occur in winter with southeasterly winds and an inversion layer, high SO_2-concentrations can be detected. These originate mainly from source areas in northern Bohemia and are transported towards the mountain ridge.
Model studies with the mesoscale meteorological model METRAS (e.g. Schlünzen, 1990; Schlünzen et al., 1996) coupled with the chemical transport model MUSCAT (Knoth and Wolke, 1997) have been performed to investigate the SO_2-situation in the *Erzgebirge*. Various meteorological conditions have been considered where high concentrations were to be expected. The model simulations were done with several emission scenarios and emission reduction concepts have been studied. The results will be presented in this paper.

REDISTRIBUTION OF CHEMICAL SPECIES IN EQUATORIAL AFRICA DURING BIOMASS BURNING EVENTS.

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During dry season linked to biomass burning occurence, aircraft measurements were achieved over Central Africa (EXPRESSO experiment) on November and December 1996. The observations have shown the composition of chemical species like NOx, O3, CO, H2O2 were not the same above the forest or savanna covers and were very heterogeneous in the boundary layer. The redistribution of chemical species is simulated using a three dimensional meso-scale model, CSU/RAMS (Regional Atmospheric Modeling System) in its nonhydrostatic version coupled with chemical model in gaseous phase. It has been initialised with ECMWF data, two nested grids are considered in order to take into account the dynamics which are associated with different vegetal covers during these days where the wind is weak at the transition forest-savana. We show the vegetation breeze plays a role in the redistribution of chemical species in forest zone which is in the monsoon flow and retrieve the non homogeneous zones of pollutants.

TRENDS AND SEASONAL VARIATIONS OF THE SUSPENDED PARTICULATED MATTER IN SPAIN

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This study presents the temporal evolution of the Suspended Particulated Matter (SPM) concentrations in the six Spanish remote stations belonging to the EMEP network. The highest value of SPM is registered in the two stations closer to the Mediterranean Sea (La Cartuja and Roquetas). It is observed an statistically significant negative trend in the SPM concentrations for two stations. Only one station (La Cartuja) has an evident seasonal cycle with a peak reached in summer and minimum in spring.

ANALYSIS CLUSTER CHARACTERIZING SO_2 AND SULPHATE PATTERS IN EUROPE

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Acid wet and dry deposition have been recognized internationatilly as one of the most important environmental issues. The potential deterioration of ecosystems and the harmful impacts on human health produced by this deposition are problems that concern goverments seriously. In this study, the annual average (1986-1994) of SO_2 and sulphate have been analyzed for the most importants EMEP stations on Europe. The objective is to discover the different patterns for these pollutants. To do this we use an analysis cluster, the method used for combining cluster was Ward's method with the associated squared Euclidean metric. A cluster solution is obtained from an examination of the resultant agglomeration schedule and dendogram.

TRENDS AND SEASONAL VARIATIONS OF NH_4^+ IN THE AIR OF SPANISH EMEP STATIONS

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This study presents the temporal evolution of NH_4^+ concentrations in the six Spanish remote stations belonging to the EMEP network. Roquetas and Logroño, the two stations closer to areas of strong N-compounds emissions, have the highest values (0.82 μgm^{-3} for Roquetas and 0.70 μgm^{-3} for Logroño). There is a statistically significant positive trend for La Cartuja station, an station close to the Mediterranean Sea in the Southeast of the Iberian Peninsula. The highest concentrations are reached in summer for four stations and in winter for two of them.

GEOGRAPHYCAL SOURCES OF NH_4^+ IN SPAIN

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In this study we analyzed the geographycal sources of NH_4^+ for the five Spanish EMEP stations. To do this we use the air mass trajectories reaching these stations and the CPFs (Conditional Probability Functions). The Iberian Peninsula is an intermediate or high source for most of the stations. Something similar happens for Continental Europe. The Atlantic Ocean and the British Islands are low or very low sources of NH_4^+ for all the stations.

GEOGRAPHYCAL SOURCES OF SUSPENDED PARTICULATED MATTER IN SPAIN

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In this study the geographycal sources of suspended particulated matter (SPM) in the five Spanish EMEP stations are analyzed. To do this we have used the air mass trajectories that arrive to the stations and the CPFs (Conditional Probability Functions). Results show that the North of Africa as well as industrial regions in the center of Spain are the main sources of SPM in Spain. Continental Europe and the British Islands are not main sources of SPM.

4D VARIATIONAL ASSIMILATION OF OZONE DATA WITH THE EURAD-CTM

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During the last decade large progress has been made in developing the technique of four dimensional variational data assimilation mainly in the context of meteorolgical forecasting. The method is based on an iteration scheme requiring forward and adjoint model runs to create a set of initial values, which is consistent with measurements distributed in time, for a subsequent forecast run.
In the field of chemistry transport modeling, the choice of correct initial or boundary values has attracted much less attention until now, though it is known that an inappropriate choice may severely reduce the simulation skill.
In this study for the first time the 4D-Var technique is applied to a comprehensive tropospheric chemistry transport model (EURAD). We introduce the massively parallel adjoint version of the CTM (which is necessary to cope with the high computational expenditure) and present first experiments with synthetically generated ozone data that show the method's capability of significantly improving the simulation. Additionally, the adjoint model is shown to be a highly suitable tool for the purposes of sensitivity analyses.

A CASE STUDY WITH MESO-SCALE TRANSPORT OF OZONE TO THE ALPINE SITE AT JUNGFRAUJOCH DURING FREETEX '96

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A FREE Tropospheric EXperiment (FREETEX) was carried out at Jungfraujoch (07°59' E / 46°32' N / 3,580 m asl) in Switzerland from April to May 1996 with the aim to study both in-situ photochemistry and transport at the alpine site. Peroxy radical measurements showed a noisy signal on 20 April due to fluctuation of the background signal, which was possibly associated with the advection of air masses with different characteristics. The ozone, CO, and specific humidity data, and the good positive correlation between them, confirmed this interpretation and suggested advection of moist, ozone-rich air. Mesoscale 3-D back-trajectories using Trajek (originally developed by the German Weather Service) were calculated, based on 1-hourly forecast data from the mesoscale operational weather forecasting model in Switzerland (Swiss Model). These provide evidence for the upward transport of ozone from the North Italy region to the Jungfraujoch within 48 hrs.

TROPOSPHERIC AEROSOL AT THREE MEDITERRANEAN SITES: ELEMENTAL COMPOSITION OF FINE AIRBORNE PARTICULATE

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Atmospheric aerosol samples were collected using a portable three stages cascade impactor sampler at three sampling sites (Bartolo Mount, 729 m and 400 m and the University Campus, 30 m height) in Castell¾n (a Mediterranean Spanish city), during a period of three months from May to July of 1996. Individual particle analysis of samples obtained was performed by a Scanning Electron Microscope equipped with an energy dispersive X-ray spectrometer (SEM/EDX), directly on the collection stages. The main goal of this work was to determine chemical composition and origin of the fine aerosol particles (0.1 ? 2.0 mm) in three different sites where there was a special interest to know the air quality condition. Following elements were found: Na, Mg, Al, Si, S, Cl, K, Ca, Fe, Zn and Ba. Several groups of particles according their chemical composition were created and its natural or anthropogenic origin determined. Authors are grateful to the Fundaci¾ Caixa Castell¾ for financial support throws the 61383 project.

EMISSION REDUCTION SCENARIOS ON DIFFERENT HORIZONTAL SCALES AND ITS IMPACT ON PHOTO-OXIDANT FORMATION

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In order to examine the effects of different realistic emission reduction scenarios on different horizontal scales on the photo–oxidant–formation the Eulerian EURAD–Modeling–System has been applied to an episode in July/August 1994. The nesting capabilities of the mesoscale EURAD–model allowed for an investigation on the European (27×27 km^2 gridsize), the regional (eastern part of Germany, 9×9 km^2) and the local scale (federal state of Sachsen, 3×3 km^2). Orographic effects on resulting ozone levels on account of channeling of wind by the upper Elbe valley are clearly visible. Furthermore effects of a high resolution landuse data set result in strong responses in meteorological fields such as high temperatures during night times over urban areas. Comparisons of model results with observations show a good agreement for all three horizontal scales considered. In order to determine the effectiveness of the different scenarios, a gridhour–analysis has been performed for ozone, an integrative method for valuating longer time intervals. The emissions scenarios for the local modeling domain have been prepared by the Prognos AG, Basel. The research project was initiated and coordinated by the Umweltbundesamt, Berlin.

THE SEA BREEZE IN THE SOUTH OF PORTUGAL: OBSERVATIONS AND NUMERICAL RESULTS

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It has long been recognised that land and sea contrasts produce sea breezes. More recently, it has become evident that other surface contrasts, like the presence of lakes and irrigated areas, may generate mesoscale circulations as strong as the sea breeze. In the last two years two field experiments were made to better characterise the sea breeze circulation in the South Coast of Portugal, in the perspective of its impact in coastal dispersion. The campaigns included 2 weeks of measurements during the summer, with a number of surface stations and regular release of radiosondes. The analysis of the observational data also included information from all automatic weather stations in the area. While results showed the expected diurnal cycle of the sea breeze in stations where the near coast is linear, they have also revealed the importance of local orography and coastal irregularity in the shaping of the temporal hodograph of low level wind. Data from inland stations was used to compute the sea breeze penetration in land and the inland velocity. The principal goal of this study was to achieve an experimental confirmation of model predictions for this type of circulations, in the case of complex mesoscale interactions between the sea breeze, coast orography, lake breezes and finally in consequence of coast irregularity. Using the observed atmospheric profiles, a number of numerical simulations were performed, using the NH3D mesoscale model (Miranda and James 1992) coupled with the soil ISBA model (Noilhan and Planton 1989), which are used to perform a detailed analysis of the coastal circulation and to identify the main mechanisms involved in its forcing.

3D mesoscale simulation over Paris agglomeration

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Paris topography is very gentle (it doesn't exceed 220m) and the city is located sufficiently far from the sea not to feel the coastal circulation. Thus,, terrain and thermally forced mesoscale circulations are very weak. Nevertheless, it is subject to strong pollution episodes, in very calm meteorological conditions, both in winter and summer.

ECLAP (French acronym for « Etude de la Couche Limite dans l'Agglomération Parisienne), a joined EDF (Electicité de France) and CNRS (Centre National de Recherche Scientifique) experiment, took place over Paris area during the 1994-95 winter. In addition to the operational meteorological network, the campaign had particularly documented 2 sites (urban vs. rural) using sodar, lidar, radio-soundings, instrumental masts and surface measurements. Its objectives were threefold : an inter-instrumental comparison, a study of the diurnal cycle boundary layer at rural vs. urban locations and to provide a documented data base to carry out 3D simulations.

We present here the last part of the experiment : some numerical simulations of two days of the ECLAP campaign. Both days were anticyclonic situation, with weak synoptic wind (2 to 5 m/s) but they are very different regarding to the wind direction, the surface and synoptic inversions strength and the cloud cover.

We have used the 3D non-hydrostatic model MERCURE (EDF). First 1D Mercure model simulations of the radiosonde data have been performed to define the meteorological initialization and the synoptic reference state of our 3D modelisation (the only adjustment made was on the fractional cloudiness and the aerosol profile in order to obtain the correct incoming solar radiation). Then 3D simulations have been conducted. We have compared the meteorological fields simulated with the data collected during the campaign. Our satisfying results allow us to consider a passive tracer (CO) evolution during the both days which concentration is known from data emission available.

EVIDENCE FOR MESOSCALE INFLUENCE ON LONG-RANGE DISPERSION

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During the first European Tracer Experiment (ETEX) tracer gas was released from a site in Brittany, France, and subsequently observed over a range of 2000 kilometers. Hourly measurements were taken at the National Environmental Research Institute (NERI) located at Risø, Denmark, using two measurement techniques. At this location, the observed concentration time series shows a double-peak structure occurring between two and three days after the release. By using the Danish Emergency Response Model of the Atmosphere (DERMA), which is developed at the Danish Meteorological Institute (DMI), simulations have been performed of the dispersion of the tracer gas. Using numerical weather-prediction data from the European Centre for Medium-Range Weather Forecast (ECMWF) by DERMA, the arrival time of the tracer is quite well predicted as well as the duration of the passage of the plume, but the double-peak structure is not reproduced. However, using higher-resolution data from the DMI version of the HIgh Resolution Limited Area Model (DMI-HIRLAM), DERMA reproduces the observed structure very well. The double-peak structure is caused by the influence of a mesoscale anti-cyclonic eddy on the tracer gas plume about one day earlier.

A CASE OF PHOTOOXIDANT PLUME MODELLING OVER PARIS AREA

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Being a secondary pollutant, ozone is not formed right over the source area of its precursors. The result is that ozone maxima are to be found in rural areas, largely undocumented. In this connection, numerical modeling appears as a unique potential tool for tracing ozone distribution even in station-devoid areas and for 3D modeling gives unique informations ozone distributions and pollutant species transport in the vertical. In the following, taking advantage of measurements collected at further rural stations operated in the large Paris region, a comparison is made between these experimental results and numerical simulations performed with MESO-NH-C (mesoscale non hydrostatic chemistry model), mainly in terms of the location and intensity of ozone maxima during a four day pollution episode in July 1996.

TRANSPORT OF OZONE AND PRECURSORS TOWARDS THE ALPS - RESULTS OF A TWO-YEAR MODEL STUDY

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The investigation of synoptic scale transport of ozone and precursors towards the Alpine region is one of the objectives of the EC research project VOTALP ending in 1998. Transport simulations are done for two complete summer half years (1995, 1996), using a Lagrangian photochemical box model, the IMPO model. The back trajectories and meteorological data used by the IMPO model are based on the data of the ECMWF weather prediction model supplemented by observations from meteorological stations all over Europe. Chemical reactions are simulated with the CBM-IV mechanism. The following main questions are treated: First, the origin of air masses reaching the Alpine region is investigated statistically. Second, areas particularly important for the ozone levels in the Alps are identified by investigating pathways associated with very high pollutant concentrations and by means of trajectory statistics. Third, it is tried to quantify what amount of ozone is formed during the transport of pollutants from the European emission areas to the Alps. The validity of all conclusions drawn from the model calculations is demonstrated using representative measurements from background stations.

OA12 Extreme weather events in the Mediterranean

Convener: Prodi, F.
Co-Convener: Eidelman, A.E.

AN INTEGRATED FORECAST SYSTEM OVER THE MEDITERRANEAN BASIN: EXTREME SURGE PREDICTION IN THE NORTHERN ADRIATIC SEA

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A previsional system has been designed and tested in order to forecast the state of the Mediterranean Sea and surges in the Northern Adriatic Sea. The system consists of a Limited Area Model (BOLAM), which computes high resolution pressure and surface wind fields, to serve as the input of a Wave Model (WAM) and of a shallow water model (POM-2D). Here we present the results of a case study which was designed to test the ability of the system to predict extreme surge events originating from cyclonic circulation over Italy. During November 1996 several surge events occurred in the Northern Adriatic Sea. The highest levels were reached in the period from the 15th to the 20th, whith one event that was among the strongest surges in the last 30 years. Nested simulations have been performed with the LAM for some of the mentioned cases, going from 30 km to 10 km resolution; the highest resolution wind field forces the WAM integration, while the pressure field, together with the wind stress computed by WAM, forces the POM. We show intercomparisons between the surface fields predicted by BOLAM, the ECMWF analysis fields and SYNOP data. while our prediction of the state of the sea will be validated with buoy data. We then compare our prediction for the free surface elevation at the entrances of the Lagoon of Venice with in situ data.

HOURLY RAINFALL STOCHASTIC GENERATION : APPLICATION ON FRENCH MEDITERRANEAN SEABOARD.

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Extreme rainfall events in the Mediterranean often result in dramatic floods. A stochastic model for generating hyetographs has been developed and tested from about fifty raingauges located on French Mediterranean seaboard. This model generates hourly rainfall events on very long periods. Owing to the period's length, it can generate extreme rainfall events of very long return periods. Results obtained show that this model is really efficient and solid. A regional parameterisation has been designed, based on four parameters, provided by daily rainfall information. This parameterisation allows to reduce problems caused by hourly rainfall data samples, and requires only daily rainfall data, more easily available than hourly data. The regionalized model does not induce additional bias as the base line model does. Daily rainfall information will be used to make a regional parameter cartography of hourly rainfall model, through a rainfall-topography correlation and a Digital Elevation Model in a GIS.

SEVERE FLOOD EVENTS IN CENTRAL EUROPE: A COMPARISON BETWEEN SATELLITE-DERIVED RAIN RATES AND RADAR MEASUREMENTS

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The analysis of severe flood events is the major topic of the EU-project "Satellite and combined satellite-radar techniques in meteorological forecasting for flood events" (MEFFE). It aims at a better understanding of those weather systems and a more reliable prediction of flash floods.
In this study a precipitation algorithm based on three-dimensional radiative transfer simulations for the frequencies of the "Special Sensor Microwave/Imager" (SSM/I) and the "Atmospheric Temperature Sounder" (SSM/T2) has been used to determine the rainfall amount over central Europe. The satellite estimates have been compared to radar data gained by the Institute of Applied Systems Technology Joanneum Research in the vicinity of Graz, Austria. The results of the comparison give some confidence that satellite-derived rainfall distributions over the central parts of Europe are sufficient for quantitatively monitoring of flood events.

Dust transport across the Mediterranean basin and simultaneous abrupt change in the free troposphere trace gases behaviour

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During four measurement years (1991-1994) 26 dust transport episodes whose origin can be referred to desert areas in Africa were recorded at Mt. Cimone (44°12' N, 10°42' E, 2165 m asl)) the highest baseline mountain site in the Northern Italian Apennines. Given its location in the Mediterranean region the site is favourable to study the long-range transport of tropospheric air masses particularly those coming from North Africa area.
On average, 6 transports per year were registered, with an average duration of 2.4 days per transport. Some of these episodes were of remarkable intensity both for the duration and for the concentration of aeolian dust. They were associated with a significant change in meteo-climatic conditions: temperatures increased, visibility decreased and dust was deposited on snow-covered or icy surfaces, with a consequent reduction of albedo.
During 14 transport episodes, of the 26 recorded, the ozone concentration decreased noticeably. In particular from 6th to 9th March 1991 an extreme Saharan desert dust transport occurred. In these days a clear reduction of surface ozone concentration and a modification in CO_2 behaviour were detected. A case study of this event regarding the ozone and CO_2 concentrations is presented.

A MODEL FOR DYNAMIC EXPLANATION OF SOME DUST EVENTS

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A mechanism for sudden release of large amounts of airborne particles from dust-laden atmospheric streams is suggested. It is destined to explain a special kind of dust storm (sharp increase of airborne particles concentration in the air) which is not accompanied by strong winds or other sharp changes in weather conditions. Seemingly, in such a case the airborne particles are not raised by winds from the earth's surface but suddenly fall out from the high level streams originating from source regions. The mechanism is based on an analytical model linking the phenomenon of the spontaneous airborne particles fallout with an instability of the dust-laden stream. The nonlinear stage of the instability represents concentration waves with an envelope in the form of solitary waves (solutions) propagating downwards from the stream. Some confirmations of the theory can be found in the literature concerning dust events in the Mediterranean.

MESOSCALE AND SYNOPTIC CONDITIONS RELATED TO THE 30 SEPTEMBER 1997 FLASH FLOOD IN ALICANTE (SPAIN)

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On 30 September 1997, a flash flood was registered in Alicante, placed at the SE Mediterranean coast of Spain. With 260 mm of precipitation in just 6 hours, the storm caused several loses in human lives. The development of a Mesoscale Convective System (MCS) started when a warm and moist air mass coming from the Mediterranean Sea mixed with a prefrontal zone related to a strong low-pressure system placed at the SW of the Iberian Peninsula. In order to show the conditions related to this development, the Skew T- Log P plot, IR and Visible NOAA images as well as the different charts for the standard pressure levels and other features of the mesoscale environment are shown.

Objective Climatology of Cyclones in the Mediterranean Region

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An objective cyclone detection and tracking analysis is performed over an 18-year period, for the Mediterranean Basin. The high resolution ECMWF data used in this study proved to be particularly useful to simplify the detection and tracking techniques and to identify sub-synoptic scale Mediterranean lows, often under-estimated in previous studies.
The major characteristics of Mediterranean cyclones are examined and compared with other Northern Hemisphere depressions. Both cyclogenesis and cyclolysis regions are identified in the domain of study. In addition, characteristics of Mediterranean depressions are shown to be quite variable for different formation areas.
Finally, a statistical analysis based on a k-means clustering procedure summarises trajectory information obtained from the 18-year climatology. The method proved to be efficient in grouping cyclone paths from similar cyclogenetic regions and with similar characteristics of movement.

EXTREME ATMOSPHERIC EVENTS FORMATION DUE TO HELICAL TURBULENCE AND ITS LABORATORY SIMULATION

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Recent studies have revealed the determining role of helicity H in the formation of turbulence modes in flows under constraints of various physical nature - under the action of Coriolis, buoyancy, shear, Joule forces. Spectral slope -7/3 corresponding to the helicity transfer rate dH/dt as the determining parameter is observed in wind spectra, in magnetohydrodynamic turbulence, etc. Important features of helical turbulence arising under the action of these factors are inverse energy transfer and a decrease in vortical viscosity described by the model and observed in experiments.
Transfer of small-scale disturbances energy into larger ones, which are long-living due to a decrease in vortical viscosity, leads to the formation of localized velocity fluctuations. Laboratory simulation of atmospheric turbulence shows that with increasing constraint, helical turbulence becomes intermittent. In this mode, intense velocity fluctuations generate a flow characterized by a velocity spectrum with a slope close to -4. In case of extreme atmospheric events, intermittence and spectra with a similar slope are also observed. The generality of these manifestations is considered as a result of helical turbulence rearrangement under the action of forcing.

A CASE OF DEEP CYCLONE ASSOCIATED TO EXTREME WEATHER IN THE MEDITERRANEAN

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On the 6th October 1996 a deep cyclone formed in the Western Mediterranean and severe weather conditions took place in a widespread area. Heavy precipitation led to rainfall amounts of 104 mm in Sardinia, 72 mm in Mallorca and 67 mm in Corsica, on the 6th, and 96 mm in Mallorca on the 7th. Gale force winds were recorded on land sites, but it seems that the maximum wind speed occurred on the sea, where wave heights up to 7 m were measured.
Satellite imagery and grid fields from HIRLAM-INM are used to make a diagnosis of the event. Effort is put to analyse the contributions of the forcing factors leading to cyclogenesis and to the occurrence of extreme weather.

ROLE OF PARAMETERIZED MOISTURE EFFECTS IN THE DEVELOPMENT OF MESOSCALE VORTICES

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Numerical simulations of baroclinic cyclones in idealized conditions are performed with a primitive equation model formulated by the author and recently presented in the literature. The parameterization of moisture effects as a reduced static stability is modified to apply only in saturated air, rather than in all ascending air as was previously done. Integration of an equation for moisture allows us to relax the assumption that ascending air is always saturated, and therefore to study baroclinic development in a more structured environment. Specifically, a situation in which moisture is confined to the lowest part of the troposphere is shown to give rise to short baroclinic modes, which may constitute a 'seed' perturbation for the formation of intense warm-core cyclones, energetically maintained by heat and moisture fluxes at the air-sea interface.

EXTREME PRECIPITATION EVENTS IN SPAIN

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In this study we analyze the meteorological patterns that produced the strongest precipitation in fifty different meteorological stations around Spain in the last 20 years. The objective is to know spatial differences inside Spain respect to the kind of meteorological patterns producing strong precipitations. Results show that mesoescale phenomena are the dominant type of pattern in the Mediterranean regions while synoptic phenomena become more important when we study extreme precipitation events in the North or Northwestern Spain.

HEAVY PRECIPITATION ALONG THE SOUTHERN RIM OF THE ALPS: A CLIMATOLOGY FROM HIGH-RESOLUTION RAIN-GAUGE DATA

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The southern rim of the Alpine ridge is particularly prone to events of heavy precipitation. The high occurrence is related to the influence from characteristic Mediterranean weather systems and the prominence of strong orographic effects. We present climatological results describing the spatial, seasonal and interannual variations of heavy precipitation in this region. The climatology is based on a unique database of daily observations at 7000 rain-gauge stations. The data was compiled from the operational high-resolution networks of all Alpine countries and covers the period 1971-1996. It is the first of its kind available in digital form.

Enhanced activity of heavy precipitation is found at three localized patches along the southern Alpine rim, where the local topographic environment and the proximity to the Mediterranean sea favours topographic channeling and moisture advection. During summer heavy events are more confined to the immediate topographic rim. Maximum occurrence is found during the autumn season, when enhanced activity also affects adjacent flatland areas. The results highlight characteristic differences in the interannual variations between convective events in summer and synoptically controlled events in autumn.

ANALYSIS OF THE HIRLAM PREDICTION FOR THE 30 SEPTEMBER 1997 FLASH FLOOD IN SPAIN

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The Spanish Meteorological Institute (INM) is a partner of the HIRLAM project (HIRLAM system version 2 currently running for the short-range forecasting). Based on the case study of the 30 September 1997 flash flood, we analyse several output fields (wind, temperature, humidity, total amount of precipitation,...) to check the performances of the HIRLAM. The model prediction presented a good agreement with the phenomenon we are dealing with, depicting clearly the high intensity precipitation areas, although the model underestimated the total amount of precipitation registered.

EXTREME WIND EVENTS IN SPAIN

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Extreme winds could be due to very different meteorological patterns. In this study we selected those days in which winds were maximum in fifty different meteorological stations around Spain in the last 20 years. Our objective was to know which meteorological pattern was responsible for these extreme wind events for the 50 stations and to compare these situations with an special emphasis to events happened in the Mediterranean area.

ON THE CHARACTER OF TURBULENT ENERGY REDISTRIBUTION IN HELICAL FLOWS

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We have studied the instability of helical turbulent flows under the action of weak large-scale inhomogeneous disturbances. It is shown that helicity increases the effective time of turbulence relaxation and causes an inverse transfer of the kinetic energy from small-scale disturbances to large-scale ones.

Instability condition for different modes in the presence of an external magnetic field is of the followinf form:

$$1/2\, k_o[1-(1-4N\cos^2\vartheta/k_o^2 v_H)^{1/2}] < k < 1/2\, k_o[1+(1-4N\cos^2\vartheta/k_o^2 v_H)^{1/2}]$$

where $k_o = \tau C/v_H$, C is an average one-point helicity, τ is the relaxation time inversely proportional to the magnetic field value, v_H is turbulent viscosity, N is Stuart number, ϑ is the angle between the wave vector and the magnetic field.

Thus, energy redistribution occurs not only between components, but also between different modes of the same direction. The obtained results well agree with the results of atmospheric observations and laboratory MHD experiments.

TURBULENCE IN THE WAKE AND VORTEX QUASI-PARTICLES

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At the overflow of uneven terrains, large-scale disturbances are generated against the background of helical turbulence that possesses similar properties in atmospheric and magnetohydrodynamic flows. To model such disturbances, we have studied the behavior of the wake behind a cylinder in mercury under the magnetic field. Under a low constraint, vortex rows in the Karman street diverge. Under an increasing constraint they converge, and the downstream decrease in turbulence energy is stopped. We have singled out components of various scales: large-scale structure, average-scale vortices, small-scale turbulence. We introduce the notion of structure as a long-range order of a turbulence ensemble. We also introduce the notion of vortex as consisting of the core and the surface region between the core and the medium. Under a growing constraint, the development of such a region leads to a significant decrease in vortex dissipation. On the whole, we have revealed that average-scale vortices in helical turbulence represent well-defined quasi-particles - they are long-living.

ON THE MARCH 1987 EXTREME COLD OUTBREAK OVER THE GREEK PENINSULA

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In the frame of this study the detailed description of an extreme cold surge that occurred on 3-13 March 1987, over Greece, is performed. This event has been ranged as the worst snowfall over the last 100 years and due to its severity and persistence it paralysed the economic and communal life of Greece for several days. Emphasis is given on the initiation phase of this event. The structural evolution of the cold surge is analysed using both observations and model results. Model simulations, have been performed with the Colorado State University - Regional Atmospheric Modelling System (CSU-RAMS). The model results permitted to diagnose the mesoscale structure of the cold outbreak as well as its vertical structure.

Different mechanisms involved in the structural evolution of the cold surge are investigated. The gustiness of the observed winds and their important departure from geostrophy are related to the role of an important isallobaric wind. The progression of this surge presented characteristics of a density current, while near the eastern slopes of the mountain barriers of Continental Greece, cold-air damming occurred leading to an accelerated flow parallel to the mountains.

NUMERICAL SIMULATION OF POSSIBLE EXTREME EVENTS DUE TO OROGRAPHY AT CYPRUS

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For mesoscale processes within the range 50-1000km, horizontal advective changes in density are small in comparison with vertical ones and anelastic condition is valid. This allows us to reduce the system of equations describing the three-dimensional problem of a stratified field motion over an arbitrary relief to a form suitable for calculation of the flow over Cyprus island. An analysis of real data two shows that there are two of the most typical synoptic processes for Cyprus are West-to-East and South-to-North wind advections. The computed overflow pattern corresponds to the general influence of Cyprus mountains on atmospheric flow, which is also apparent from comparison with map of precipatation distribution. The analysis of vertical sections shows that in the presence of a tendency to overflowing the principal Cyprus mountains, Troodos and Macheras, from the South, the formation of "blocking" zones is possible. The admixtures from anthropogenic pollution sources may be accumulated in these zones. The zones of the highest ruggedness of the flow surface approximately correspond to maximum precipitation zones, where strong rains may occure The calculations for the Zygi region reveals a possibility of stagnant (weakly aerated) zones arising to the South of the Profitis Elias ridge. The zones of "sinking" flow may arise between mountains according to initial conditions. It points to the fact that even purely hydrodynamic modelling of the overflow of different mountains regions of Cyprus may supply information both on the sites of deceleration of external flow, (where the development of urban infrastructure and energy industry is undesirable).

AIR-SEA FLUXES DURING THE DEVELOPMENT OF A MEDITERRANEAN CYCLONE

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A tri-modular model of the coupled atmosphere-sea system (called MIAO) has been developed and implemented in the Mediterranean Sea. The model consists of the meteorological limited area model BOLAM, the coastal ocean circulation model POM, and the ocean wave model WAM. The three models are coupled because the sea surface temperature computed by POM and the sea surface roughness computed by WAM are used by BOLAM which, in turn, computes the surface fluxes that force both POM and WAM. Consequently, the MIAO model computes the air-sea fluxes, accounting for the feedbacks of the sea on the atmosphere. The role played by heat and momentum fluxes during a case of cyclogenesis in the western Mediterranean (6-8 october 1996) is discussed. It is shown that the effect of the coupling is to diminish the cyclone intensity, by reducing the sea surface temperature and, consequently, the surface heat fluxes. This attenuation compensates the overprediction of the cyclone strength by the uncoupled computation, and favourably compares with the observations.

OBSERVATIONAL AND MODEL ANALYSIS OF A SEVERE FLOODING EVENT OVER GREECE

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On 11 and 12 January 1997, a major precipitation event occurred over the Eastern Mediterranean and especially over Southern Greece. Heavy precipitation (more than 300 mm of accumulated rain within 24 h) provoked severe damages over Southern Greece in Peloponnisos, where several cities experienced severe flooding. Heavy precipitation (200 mm within 24 h) caused also severe problems in the road network and some bridges collapsed in Central Greece, while in Athens flooding was reported in some suburban areas (more than 70 mm of rain within a few hours).

This event is studied through both observational and model analysis. The observational analysis is based on surface, upper air and satellite data as well as on ECMWF analyses. The mesoscale analysis of the event is based on nested-grid simulations performed with the Regional Atmospheric Modelling System (RAMS). The role of topography of Greek Peninsula on the enhancement of convection as well as the role of surface fluxes from the relative warm Mediterranean waters towards the atmosphere is investigated. Apart the analysis of the dynamics of heavy rainfall, the role of Conditional Symmetric Instability on the development of a cloudband observed at the edge of the cold frontal surface is discussed.

THE ROLE OF SURFACE HEAT FLUXES IN THE DEVELOPMENT OF A MEDITERRANEAN "HURRICANE"

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A case of an intense small-scale cyclone development over the Western Mediterranean, occurred in the period 6 to 8 October 1996, is simulated numerically with a mesoscale model. The vortex exhibited a hurricane-like structure, with a spiral cloud structure and an eye clearly shown in the satellite imagery. The cyclone trajectory and intensity are documented both by the satellite pictures and by surface observations during the storm passage over the Sardinia island. The synoptic situation at the initial time shows a potential vorticity maximum at upper levels, where a cut-off low enters the Western Mediterranean from the north-west. In the development phase, the cyclone is of mixed baroclinic-convective type, while in the mature stage is maintained by the latent heat release. The model is successful in predicting the initial evolution and trajectory of the storm, but overpredicts the cyclone intensity when a climatological sea surface temperature is prescribed. However, a strong sensitivity of the pressure minimum to the sst is demonstrated by numerical experiments. The presence of positive fluxes of sensible and latent heat at the sea surface is essential for the cyclone growth and maintenance. The cyclone track over the sea during the deepening phase shows a high degree of unpredictability, depending on model characteristics and parameterization schemes.

RECONSTRUCTION OF HEAVY RAINFALL EVENTS OVER THE PO BASIN FROM 1868 TO THE END OF THE 19TH CENTURY

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The southern part of the Alpine Region is an area where heavy rainfall events are rather frequent and where a number of disastrous floods have been reported in the last 100/150 years. Within this context the purpose of the presentation is to show how the data and the other information available at the present allow for this area rather detailed reconstruction of meteorological scenarios of heavy rainfall events just starting from 1865. The problem of the reconstruction of these scenarios can be divided in two periods: before and after 1879, when the Italian Central Office for Meteorology began to draw daily isobaric charts. In the presentation the availability, quality and homogeneity of the data will be discussed for both periods and a methodology of reconstruction of isobaric charts over Italy and Europe for the period 1865-1879 will be presented. Moreover some important events both of the first and the second period will be illustrated. They include the September-October 1868 event, the October 1872 event, the May 1879 event and the September 1882 event.

SSM/I ANALYSIS OF TWO "HURRICANE-LIKE" VORTICES OVER THE MEDITERRANEAN SEA

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An analysis of the microphysical structure of two sub-synoptic "hurricane-like" vortices over the Mediterranean Sea has been carried out using the Special Sensor Microwave/Imager (SSM/I) brightness temperatures at 19.35, 37.0, and 85.5 Ghz. SSM/I data have been analyzed by means of a physically-based precipitation profile Bayesian retrieval algorithm making use of a cloud radiation database, the cloud portion of which is based on a numerical simulation carried out by means of the three-dimensional, time-dependent cloud/mesoscale model University of Wisconsin - Non-hydrostatic Modeling System, while the multi-spectral upwelling microwave brightness temperatures have been computed by using the detailed thermodynamical and microphysical outputs of the simulation as an input to a three-dimensional radiative transfer scheme. Results will be analyzed and discussed taking into account the dynamical characteristics of the same events, that are described in the companion paper by O. Reale.

A CASE OF EXTREME PRECIPITATION IN SOUTHERN PORTUGAL

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Cases of very intense precipitation are not very common in Portugal. The fall of 97 has been exceptional in this respect, with a few extreme cases with large impact in terms casualties and property loss. Various events, which occurred in a predominantly southwesterly flow, have been responsible for significant flooding in many places. One of these events, produced local precipitation rates of the order of 100 mm/h during 3 hours, in a small area of higher orography, leading to severe flooding. This event was not predicted by the operational models and has been selected for a case study. Some preliminary results of this case study have been performed, including diagnostic studies of the background flow field, analysis of available data and numerical simulations with different settings.

STUDY OF THE HURRICANE-LIKE MEDITERRANEAN CYCLONE OF JANUARY 1995

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The development of a hurricane-like cyclone over the Mediterranean sea has been studied using observational data and the UKMO Unified Model. The formation of the Mediterranean cyclone took place in the morning of the 15th of January 1995 over the sea between Greece and Sicily. Strong surface fluxes and, as a result, deep convection existed in the vicinity of the cyclone during its lifetime. Its track was influenced by the fluxes and the flow in the wider region. The forecast of the mesoscale and limited-area models reproduced the general characteristics of the actual system as they appeared on surface and upper-air charts and on satellite imagery. The investigation of the cyclone's characteristics gave strong evidence to support the initial assertion that it was similar to tropical cyclones and some polar lows (including an 'eye' and a warm core). Baroclinic instability did not seem particularly important, although the formation took place at the edge of a baroclinic zone. A numerical experiment showed that the vortex did not develop in the absence of surface heat and moisture fluxes. Another experiment showed that sensible and latent heat fluxes were equally important in its development.

CASE STUDY OF A FRONTAL PASSAGE OVER ISRAEL

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Fronts cause sharp weather changes over the eastern Mediterranean in winter. Heavy rains, thunderstorms, hail, floods in Israel are connected with the frontal passages. Nevertheless the detailed studies concerning the mesoscale structure of fronts in this region are not frequent i literature. The presented poster describes the evolution in the tropospheric conditions during the passage of an active front on the 9.11.90 over Israel, causing rainy weather. We concentrated on the details in the structure of temperature, humidity and wind fields, using radiosounde data obtained in a series of special observations near kibbutz Dorot. Based on meteorological and synoptic data available from the Israel Meteorological Service, peculiarities in precipitation distribution, connected with a front are analyzed. The results are compared with a hydrodynamic front model developed at the Desert Meteorology Unit of the Institute for Desert Research.

UPPER-LEVEL PV STRUCTURES AND HEAVY PRECIPITATION SOUTH OF THE ALPS: A SENSITIVITY STUDY

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An examination is undertaken of the influence of small scale tropopause-level structures upon the numerical prediction of a heavy precipitation event. To this end a method is developed to generate a range of different initial states that represent perturbations of these upper-level structures. The approach is founded upon the potential vorticity (PV) perspective of the flow, and entails a modification of the upper-level PV configuration of an initial state based upon the PV-difference between the analysis and a preceding short-range forecast. A set of modified fields are then constructed so that each member includes a combination of seminal PV-elem ents.
To illustrate the approach a study is undertaken of the Piedmont flood of November 5-6 1994. Simulations of the event reveal a significant sensitivity of the resulting prediction to the initial specification of the upper-level PV distribution and thereby provide some indications of its predictability limits imposed by uncertainties in the initial specification of the upper-level flow.

DYNAMICS AND CLASSIFICATION OF TWO SUB-SYNOPTIC SCALE "HURRICANE-LIKE" VORTICES OVER THE MEDITERRANEAN SEA

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Two intensely convective sub-synoptic scale vortices developed over the Mediterranean Sea on 30-31 October 1997 and on 5-8 December 1997. Fluxes. strong precipitation rates, small-scale, alignment between cutoffs at all levels with sea level pressure minimum, axysimmetric wind structure, lack of vertical shear on the scale of the vortex, suggest a "hurricane-like" structure.
Hurricane-like cyclones have been detected in the Mediterranean since the early '80s: although clearly different from the well-known Mediterranean baroclinic lee cyclones, their nature is still controversial: sometimes the same event is regarded by different authors as tropical-like or as a polar low.
Comparisons between the two cyclones and other apparently similar events. reveal two distinct categories of hurricane-like storms in the Mediterranean. Barotropic instability related with strong horizontal shear plays a major role in one category, a mid- and upper- tropospheric cold dome is needed for the other. As a consequence, their thermal structure appears different, since the former displays a clearly recognizable warm-core, not present in the latter. A classification of hurricane-like systems in the Mediterranean, based upon dynamics, is presented. The microphysics of the vortices is analyzed in the following paper by Mugnai et. al.

OBJECTIVE CLASSIFICATION OF THE HEAVY RAINFALL PATTERNS IN MEDITERRANEAN SPAIN

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A dense daily precipitation data base, extending from 1964 to 1993, has been created for the Mediterranean regions of Spain. It is composed of complete and homogeneous series at 410 raingauge stations. Using this data base, the main torrential centres have been identified by means of seasonal and yearly maps of extreme events, and the calculation of recurrence intervals. In second place, the main spatial patterns controlling torrential daily rainfalls have been derived. This has been done by applying cluster analysis on the most relevant principal directions extracted from a principal components analysis of the between-day correlation matrix. The obtained patterns are quite definite and clearly display the dominant role exerted by the complex topography and its connection with the main rain bearing flows. Interseasonal variability shows a different behaviour depending on the zone. The western patterns, largely stimulated by Atlantic flows, have similar incidence in winter and autumn. On the contrary, the eastern patterns, which are strongly influenced by the Mediterranean dynamics, dominate in the fall season.

ATMOSPHERIC FLOW REGIMES ASSOCIATED WITH A PIEDMONT-LIKE LOW-LEVEL JET

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A south-westerly pre-frontal low-level jet advecting moist air from the western Mediterranean to the southern slopes of the Alps appears to be a typical feature in Alpine flooding cases and was also observed in the Piedmont case of Nov 1994. Such a jet is important because it provides the pertinent moisture flux, but it also determines the nature of the atmospheric flow response and the orographic lifting leading to the triggering of convective and/or stratiform precipitation. Since the flow is usually around the Alpine orography rather than over it, mechanisms leading to deep lifting are of particular interest. To identify the relevant flow regimes, series of numerical experiments with and without an idealised low-level jet are carried out. Initially, dry dynamics is used to gain insight into the basic mechanisms in such settings. Results indicate that the strength of the low-level jet has to exceed a critical value to be able to cross the model Alpine orography and to induce deep orographic lifting. The results thus emphasise the low-level jet's rôle in determining the atmospheric flow response.

A CLIMATOLOGY OF MESOSCALE CONVECTIVE SYSTEMS SOUTH OF THE ALPS

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Mesoscale Convective Systems (MCS) are known to contribute to a large part to heavy rainfall and floods. Nevertheless, there are very few objective and long-term climatologies of such systems in Europe; this may be explained by the tedious character of manual tracking and characterization of these systems.

An automated system has hence been developped, which uses a radiative temperature threshold for defining cloud shields in Meteosat infra-red images. It handles splits and merges of cloud shields and successfully tracks cloud systems which are as small as 1000 km^2. The tracking quality prove to be largely insensitive to the temperature threshold value, and threshold effects are also accounted for.

For the identification of those of the cloud shields which are convective, a decision system has been designed. It is based on temperature gradients at the cloud shield edges. Testing it using lightning data as ground truth allows to exhibit a 95% efficiency.

These tools have been used to compute a 5 year long climatology of MCS in the region south of the Alps. It addresses topics like preferred location of convection triggering, typical scenarii of MCS development in relation to weather types, and slow-moving systems.

CYCLONIC ACTIVITY AND SEVERE JUGO IN THE ADRIATIC

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The beginning of April 1996, was characterized by very strong jugo winds and heavy precipitation along the Adriatic coast. Synoptic and satellite diagnostics, as well as numerical simulation with real data, show that strong cyclogenetic processes took place during the observed period. It is also shown that processes over the Adriatic, depending on general synoptic situation, can be masked by the processes over the western Mediterranean. Although from the synoptic point of view they belong to the same process on the lee side of the Alps, mesoscale an local characteristics of the flow and precipitation distribution are strongly influenced by the orography of Dinaric Alps and by humid processes over the Adriatic sea.

MONITORING OF RAINING SYSTEMS USING SSM/I AND METEOSAT DATA

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A method is presented using rain information from the SSM/I radiometer in order to correlate Cloud Top Temperatures (CTT) from METEOSAT-IR measurements to rain rates. SSM/I retrievals provide rain rates over the North Atlantic and Mediterranean Sea with a considerable high accuracy. Furthermore it is possible to distinguish between convective and stratiform cloud systems. This information is used in order to perform a correlation between Meteosat CTT's and rain rates for convective cases. Based on the relation found this way convective rain systems can be monitored, taking advantage of the high temporal and spatial coverage of Meteosat data. Using horizontal structure information from the Meteosat images, the assignment of SSM/I- rain-rates to CTT absolute values and horizontal variance can be refined. Once the rain system is identified it might be tracked as it advances onto land surface. Also similar patterns in the CTT /horizontal CTT-variance domain might be interpreted as rain systems where no SSM/I information is available (e.g. costal areas).

HEAVY RAINSTORMS OVER NORTH AFRICA AND THE MID-EAST AND THEIR ASSOCIATION WITH THE SUBTROPICAL JET

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The study deals with heavy and widespread rainstorms over the Mediterranean and the arid northern Africa. Theey are related to disturbances in the subtropical jet. The ECMWF initialized data, together with ground observations and satellite imageries, are used to study the the23-24 Dec 1988 rainstorm, associated with a pronounced intrusion of an upper-level mid-latitude trough down to 25°N latitude.

The analysis points at two factors: 1) The intensive moisture transport in the mid- and higher-levels from the tropics by the meridional wind component ahead of the upper-level trough, which is enhanced by an ageostrophic transverse flow, associated with the acceleration of the air parcels there. 2) The mid-troposphere ascendance induced by the divergence due to the positive vorticity advection ahead of the upper-trough. Both effects are larger in the subtropics due to both the high wind speed and the smaller Coriolis parameter there, as compared to the mid-latitudes. Indeed, the divergence there reaches $6\times10^{-5}s^{-1}$ at the 200 hPa, and vertical velocity there is about 10^{-1} ms^{-1} at 700 hPa level, where the most active cloudiness is found.

It is argued that these rainstorms result from exceptional intrusions of pronounced mid-latitude troughs toward the subtropics. In such a case, the subtropical jet is 'broken' into two branches. The upward motion, induced at the anticyclonic sector of the eastern branch's entrance, enhances the tropical convection there, and intensifies the jet speed downstreem, while enhancing the moisture supply there. This positive feedback mechanism may explain the exceptional intensity encountered in such storms.

OA13 Cyclogenesis and fronts: FASTEX

Convener: Chalon, J.-P.
Co-Convener: Thorpe, A.J.

PRECURSORS IDENTIFICATION OF FASTEX IOP17 CYCLOGENESIS USING POTENTIAL VORTICITY INVERSION CONCEPT

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During the last few years, the theoretical study of cyclogenesis has experienced a remarkable renewal. The new data required by today's concepts was to be provided by the observations collected during the FASTEX field experiment. This paper presents one of the very first dynamical result. It reveals the unexpected importance of a low level precursor in IOP 17 cyclone, exhibited using a new objective diagnostic tool: the manipulation of initial conditions through quasi-geostrophic potential vorticity and its inversion. Using the semi-qualitative reasonning, the case looked like a straightforward triggering of the cyclone by an upper tropospheric disturbance.

MECHANISMS FOR MID-LATITUDE CYCLONE DEVELOPMENT

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The initial development of localized cyclonic perturbations is investigated in a hierarchy of models. The work presented explores the dependence of the linear evolution on the perturbation scale, structure and location. The mechanisms involved in the rapid kinetic energy growth and formation of deep systems are explained in terms of potential vorticity, the effects of changing perturbation phase tilt and Rossby wave propagation. Perturbations that are confined both vertically and horizontally in streamfunction and located away from boundaries yield the largest transient kinetic energy growth. Transient growth rates in excess of the fastest growing normal mode can be achieved for perturbations having no phase tilt with height. Basic states with positive meridional gradient of potential vorticity give rise to perturbation growth accompanied by upward propagation. Perturbations located at low levels benefit from this propagation, exhibiting earlier deep system formation downstream and sustained growth, whereas perturbations located at upper levels take much longer to engage the surface boundary. This work offers a fundamental physical basis for understanding optimal perturbations; many aspects of the structure and evolution of singular vectors calculated by the ECMWF can be understood in the context of this idealized work. The role of diabatic processes as well as the relevance of these mechanisms in storm track organization using more realistic models of the atmosphere will be presented.

ADJOINT-BASED TARGETED OBSERVATIONS DURING FASTEX : IMPACT AND FEASIBILITY STUDIES

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One of the objectives of FASTEX was to study the sensitivity of East Atlantic cyclones to so-called "targeted observations". Adjoint based sensitivity calculations were one way to search for the areas at initial time that may have the largest impact on the evolution of the studied low. During FASTEX, several adjoint products, computed from different centers (NRL, NCEP, CNRM), were available in real time and were used to place the additional observations (NOAA GIV, USAF C130, Learjet and ships). These FASTEX observations provide the first opportunity to examine the impact of special "adaptive observations". In this study, the IOP17 and IOP18 are investigated. The main goal of this work is to show how additional observations could improve the forecast. The first results prove the dominating effect of the initial error projecting on the first two leading singular vectors (defining the first unstable plan). The second results is that the adaptive observations feasibility greatly depends on the quality of the assimilation system and of the model used. In addition, it is very difficult to correctly analyze all the non-synoptic data (like many dropsondes and ships soundings) with the current assimilation system (Optimal interpolation or 3Dvar). The first 4Dvar tests are presented to demonstrate the impact of the assimilation quality on the adaptive observations feasibility.

ADJOINT-BASED TARGETED OBSERVATIONS DURING FASTEX : IMPACT AND FEASIBILITY STUDIES

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THREE DIMENSIONAL STUDY OF DYNAMICAL AND THERMODYNAMICAL FIELDS DEDUCED FROM AIRBORNE DOPPLER RADAR AND DROPSONDE DATA

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The FASTEX experiment allowed the observation of mature synoptic and subsynoptic cyclones over the North Atlantic Ocean.
The case of the 17 February 1997 was sampled by an airborne doppler radar on board of NOAA-P3 during more than six hours. At the same time, many dropsondes were launched by the UK-C130 aircraft in order to cover clear regions of the deepening wave. These various nested data are then used to retrieve the three dimensional physical fields.
For this study we focus on the dynamical and thermodynamical aspects for synoptic, meso and convective scale, in order to describe the multiscale processes involved in the deepening of the wave. Main results about scale interaction will be presented.

REDUCED UPPER-TROPOSPHERIC POTENTIAL VORTICITY

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The modification of Potential Vorticity (PV) by diabatic heating through latent heat release in clouds, has been known about for some time. Traditionally it has been thought that a dipole of PV anomalies is produced, positive below the heating maximum and negative above. Much work has been done on the role of the positive anomaly in the development of its parent cyclone, but much less has been said about its sibling, the reduced upper-tropospheric PV (RUPV). Basic ideas on the formation and characteristics of RUPV will be discussed both in the context of theoretical arguments and real data. This will include a comparison of the PV-dipole theory and more recent suggestions of, for example, Wernli and Davies (1997). Examples of RUPV anomalies in FASTEX cases will be shown. The role of RUPV in atmospheric dynamics is elucidated using results from trajectory calculations and attribution techniques. This will include discussion on the possible connections with downstream development, and jet-streak phenomena.

MESOSCALE ANALYSIS OF ARC RAINBANDS IN A DRY SLOT

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A series of almost concentric, arc-shaped narrow rainbands was observed travelling at 140 km/h and producing severe wind gusts over parts of England. Their structure and environment have been analysed using radar and satellite imagery, mesoscale-model diagnostics, surface observations and additional radiosonde ascents obtained during the Fronts and Atlantic Storms Track Experiment (FASTEX). The multiple rainbands are shown to have been triggered beneath the exit region of a strong upper-level jet within part of a dry intrusion characterised by a mesoscale vortex/cold pool. The rainbands were associated with rather shallow convection which formed where this feature overran warm-sector air. Perhaps because there was no statically stable layer at low-levels to sustain any wave activity, the associated mesoscale pressure pertubations were rather small and it is necessary to look for explanations other than inertio-gravity waves to account for the quasi-periodic nature of the rainbands.

THE FRONTAL WIDTH PROBLEM

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A principal characteristic of an atmospheric front is the transition zone between air masses of disparate properties. This zone. characterized by turbulent dissipation of kinetic energy, is not adequately described by either analytical or numerical models. In particular. numerical models simulate frontal zones only to the extent that their development and structure is permitted by the finite resolution and prescribed eddy diffusivity inherent in the model. This talk will examine the physical processes that appear to be associated with the presence of a frontal transition zone, based on various field investigations carried out in the Great Plains of the central United States. All frontal activity considered is devoid of precipitation, and the principal physical processes that are considered are the rate of turbulent dissipation of kinetic energy, frontogenetical forcing by a deformation field and the generation of inertial-gravity waves in the field of flow. Eddy diffusivity is not a relevant parameter. The energy dissipation rate (ϵ), the deformation parameter (α), or the growth rate (σ), and the Brunt-Väisälä N and Coriolis f frequencies are used to introduce new scalings for both the horizontal and vertical scales of the frontal transition zone. These limiting scales are directly related to physical processes that involve wave/turbulence interactions as frontogenesis proceeds.

DISCRETE FRONTAL PROPAGATION INDUCED BY CONVECTION

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A case example demonstrating that surface fronts can propagate in a non-continuous manner is presented. The event occurred as a cold front encountered a surface-based mesoscale area of convectively-generated cold air over the central United States (Oklahoma and Arkansas). A new frontal circulation formed on the downstream boundary of the modified air, about 400 km ahead of the original front, and underwent rapid intensification while the original front dissipated. The event occurs over gently sloping terrain, away from steep topography.

This case was simulated using the fifth generation Penn State/NCAR mesoscale model (MM5) to gain insight into the processes that produced the discrete movement. Model results indicate that the frontal system was not able to penetrate the layer of cool stable air generated by the deep moist convection. It was also found that differential radiational heating as a result of the clear-to-cloudy boundary associated with the convection helped create a strong baroclinic zone well ahead of the front. The new frontal circulation formed in this baroclinic zone. Eventually, upper-level support adjusted to the new low-level frontal circulation and enhanced its development while suppressing the original frontal feature.

OVERVIEW OF THE LIFE CYCLE OF A FASTEX CYCLONE: IOP 17

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The overview of one of the best documented life cycle of a FASTEX cyclone (IOP 17, from 16 to 20 February 1997) is presented using operational ARPEGE analyses, satellite images and special FASTEX observations. The presentation will first focus on processes contributing to the triggering of the surface low and coming with the arrival of an upper level short wave (potential vorticity anomaly) over the eastern coasts of the United States, e.g. the reinforcement of the steepness of the main baroclinic zone and the onset of a direct and transverse ageostrophic circulation in the intensifying entrance region of the the upper level jet. It is then discussed the impact of latent heat release in the developing surface low on the formation of a dual upper level jet and on the behavior of the upper level potential vorticity anomaly. The formation of a surface frontal wave in the wake of the surface low is investigated. The end of the life cycle, involving FASTEX research aircraft flights in the Mesoscale Sampling Area, will finally be discussed. The presentation will also synthetize the dropsonding and radiosounding observations performed by aircraft and ships respectively, and mention other works in progress on the POI 17 at CNRM and LA and that will be presented in separate talks.

ROLE OF FRONTOGENESIS ON FRONTAL WAVE DEVELOPMENT IN FASTEX

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Two major mechanisms of frontogenesis, deformation and shear, are important in frontal wave cyclone development. Horizontal deformation can suppress the nonlinear wave development. Using an analytic model, Bishop and Thorpe (1994) showed that large strain rates inhibit any wave slope amplification. For real cases, this ambient strain can be measured using the vorticity-divergence attribution method developed by Bishop (1996). This technique permits us to confirm the crucial role of such strain on the evolution of FASTEX cases (IOPs 5, 7, 9, 11a, 12, 16, 17, and 19).
Horizontal shear, in the presence of an along-front thermal gradient, is also an important mechanism of frontogenesis. Using an Eady model, Joly and Thorpe (1991) showed in cases of large ambient shear, frontal waves have growth rates smaller than the front itself, and thus would not develop. We have extended the domain-independent Bishop attribution method to a geopotential field partition. This leads, via a non-linear balance condition, to the estimation of the ambient along-front temperature gradient and hence the shear. The role of such shear is discussed as well as the relative contributions of the two frontogenesis mechanisms for the above cited FASTEX cases.

DISCRETE FRONTAL PROPAGATION IN A NON-CONVECTIVE ENVIRONMENT

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This study explores the means by which frontal movement can change in response to horizontal inhomogeneities in the environment through which the front propagates, specifically addressing discrete frontal propagation. It is shown that a front encountering a strongly varying lower-tropospheric thermal structure can be expected to respond to the environment such that it manifests itself at the location most preferable for its internal dynamics at any given time, without necessarily propagating in a continuous manner through the region.

For the purposes of this study, one example of discrete frontal propagation in a purely non-convective, wintertime environment is examined in detail. Observational analyses and mesoscale numerical simulations of the event using the PSU/NCAR mesoscale model (MM5) are presented. It is shown that discrete frontal propagation does occur at the surface, with the front disappearing and then reappearing some 200 km ahead of its previous location. The upper level trough associated with the front propagates continuously, apparently independent of the surface evolution. A strong surface-based thermal inversion and a pre-frontal plume of warm, moist air that leads to widespread precipitation into the dry airmass ahead of the front are responsible for the horizontal inhomogeneities in this case.

OBSERVATIONS AND SIMULATIONS OF A DEVELOPING FRONTAL WAVE DURING FASTEX IOP 16

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Frontal waves present many difficulties for both subjective and numerical prediction. Aside from their development the associated mesoscale structure and weather vary greatly between systems. There is a need for a theoretically-based approach to understanding, both subjectively and for the refinement of quantitative models.
A rapidly developing frontal wave was the subject of IOP 16 of FASTEX on 17th February 1997. Observations were made with both dropsondes and airborne Doppler radar in 6 parallel runs designed to carry out a systematic survey of the main active part of the wave.
UK Met. Office's LAM version of the Unified Model gave reasonably good forecasts of the event. A set of further integrations have been made with the model to investigate factors contributing to the development and the mesoscale structures simulated and observed. Results from these studies will be presented.

COMPARISON OF MESOSCALE DYNAMICAL STRUCTURES FROM FASTEX DROPSOUNDINGS WITH FORECAST MODEL FIELDS

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A central objective of the Multiscale Sampling Area component of the FASTEX experiment was to document mesoscale dynamical structure from a range of weather systems using systematic survey flight patterns of dropsoundings from the Meteorological Office's C130 aircraft. Data from these have provided a substantial body of frontal cross-sections which provide an unprecedented opportunity to evaluate numerical models and test their parametrizations of cloud and precipitation. A methodology is presented for such comparisons of observed and simulated structure, in which the outcome of frontogenetic and diabatic processes is expressed in terms of the resulting thermodynamic and dynamic structures. This approach is then applied to integrations from the UK Meteorological Office's Unified Model for several FASTEX events. Results from these comparisons to date will be presented.

UPPER LEVEL DYNAMIC OF A FASTEX CYCLONE: IOP 18

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The FASTEX IOP 18 (22-23 February 1997) is a cold air cyclogenesis that first developed north of the main baroclinic zone and ended as a classic cyclogenesis, by interaction with this baroclinic zone. The presentation is devoted to the upper level dynamics in the initial phase of the life cycle, e.g. the period ending with the triggering of the surface low over the Labrador Sea. Based on ARPEGE operational analyses, FASTEX- ships and aircraft observations as well as satellite data, the presentation will relate the trajectory to the behavior of an upper level potential vorticity anomaly involved in the triggering mechanism. In particular, structural changes and upper level frontogenetic processes that develop as the potential vorticity anomaly brings closer to the cyclonic-shear side of the polar jet stream will be documented using diagnoses and observations. Confluence and cold advection forcings of a transverse and direct ageostrophic circulation giving way to a very deep tropopause fold observed with dropsondes launched by the NOAA-G4 aircraft on the southern side of the potential vorticity anomaly will be documented. The presentation also mentions links with two other separate talks that investigate the sensitivity of the triggering mechanism to boundary layer processes using low level observations and a potential vorticity inversion method.

ROLE OF SALIENT PV-ELEMENTS IN AN EVENT OF FRONTAL-WAVE CYCLOGENESIS

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A study is undertaken of the relative role of distinctive upper- and lower-level atmospheric structures in one event of frontal wave-cyclogenesis. The structures considered are those traditionally deemed to be important in cyclogenesis, and they are interpreted here as salient elements in the atmosphere's potential vorticity (PV) distribution.
A 'successful' forecast with a limited area model is adopted as a surrogate for the actual event, and a sequence of simulations is undertaken with modified initial conditions corresponding in each case to the removal of one (or more) of the salient PV-elements. This aproach constitutes diagnosis by PV-dismemberment. It provides a direct indication of the relative significance of various precursor conditions, permits an incisive comparison of various extant theories of cyclogenesis, and pinpoints the particular PV-elements influenceing the event's predictability.
It is shown that a simulation that replicates the realised cyclone requires an adequate representation both of specific fine-scale PV-features at tropopause levels and of the continuous generation (and destruction) via cloud-diabatic effects of a low-level PV-element.

FRONTAL WAVE DEVELOPMENT IN NUMERICAL MODEL FORECASTS

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A new automated method for locating the tips of frontal waves using gridded numerical model data has been devised. The methodology equates to manual methods of analysing waves on synoptic charts: waves are identified at those meeting points of cold and warm fronts where there is also cyclonic rotation in the cross-front wind. Using the new method a comparison will be made, for the FASTEX period, between forecasts and analyses of the U.K. Met. Office limited area model, in terms of their representation of frontal waves. Systematic errors in the handling of these features in model forecasts will thus be described, with regard to spatial distribution, forecast lead-time and surrounding synoptic-scale environment. Possible reasons for the errors will be discussed.
One way in which a model can potentially anticipate wave development, on a front, is by computing the stretching deformation, due to the environmental flow, that would act on any incipient wave. If this deformation is below a theoretical critical threshold value then wave development can occur. A new method, utilising objective fronts, has allowed this calculation to be automated. The potential for such a method to help reduce model systematic errors will be discussed with reference to problem cases from the FASTEX period.

IDENTIFICATION OF TROPOPAUSE-LEVEL THERMAL ANOMALIES FROM TOVS OBSERVATIONS

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An important issue of the FASTEX experiment concerns the genesis mechanism and more specifically the existence of preexisting upper-level anomalies. Observations from the satellites of the TIROS-N series, equipped with the HIRS-2 (High Resolution Infrared Radiation Sounder) and MSU (Microwave Sounding Unit) radiometers, allow for the determination of the so-called Temperature of the Lower Stratosphere (TLS) as it has been defined in the 3I (Improved Initialization Inversion) approach to the inversion of the Radiative Transfer Equation and which represents the temperature around the tropopause.
For several FASTEX Intensive Observing Periods, anomalies in TLS have been studied and their trajectories compared to other independent diagnostics : MSU 3 brightness temperature, 2PVU surface potential temperature computed with the ARPEGE model and water vapor imagery. While trajectories are generally similar, significant differences may appear, especially in the incipient stage, with TLS anomalies observed later than potential temperature anomalies. This point as well as the respective capability of MSU3 and of the TLS approach to detect upper-level precursors will be discussed.

AIRCRAFT OBSERVATIONS OF FRONTAL CIRCULATIONS AND STRUCTURES IN FASTEX

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This paper provides an overview of frontal circulations and structures observed during the FASTEX project. The two month FASTEX field effort provided numerous observations of cold and warm fronts, frontal waves and banded convective structures. Airborne Doppler radar observations are used to describe frontal rainband precipitation structures and circulations in the frontal region. In-situ and dropsonde observations describe the accompanying frontal temperature and humidity structures. The observed frontal intensities ranged from weak, slow-moving cold fronts in light wind situations to fast-moving intense cold fronts in high wind situations. Most FASTEX frontal structures were observed to be extremely shallow, frequently only about 1 km deep. The cold-frontal rainbands included a wide variety of frontal wave scales. At the small scale were waves on the scale of the individual frontal rainbands. Somewhat larger were waves corresponding to groups of three to four frontal rainbands, with kinks in the front between the rainband groups. At a large scale were frontal waves, which included rainband structures different from typical cold frontal rainbands. The different scales of frontal waves may correspond to the different dynamics of the different scale processes. Also presented are some observations of very shallow cold air flows, extending a great distance into the warm sector air mass.

THE ROLE OF THE TROPOPAUSE IN DESTABILIZING THE ATMOSPHERE

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The evolution of a convective system, embedded within an extra-tropical cyclone, which passed over Southern England in May 1995 has been investigated using the UKMO mesoscale model. This model has a 17km horizontal resolution and is on approximately a 1500km square domain over the British Isles. The system has associated with it a significant lowering of the tropopause (PV=2PVU down to 600mb) and some convective rain. Idealised theoretical studies have shown that an upper PV anomaly leads to a decrease in static stability. The effect is quantified for this case study by using piece-wise PV inversion. The method used by Davis and Emanuel (1991) is followed and extended for this inversion. The use of different boundary conditions at the lower surface are investigated, and the implications of these different boundary conditions on the ideas of attribution are discussed. Both the static stability and the wind shear attributable to the tropopause fold will be discussed, as will the consquence of such flow patterns in producing differential rotation.
The FASTEX data set provides ideal high-resolution data for further testing of these ideas.

THE FASTEX DATABASE: A LARGE ARCHIVE FOR NORTH ATLANTIC CYCLONES STUDIES

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A large part of the special data sets collected during the Fronts and Atlantic Storm Track Experiment (FASTEX) field phase in January and February 1997 is available for studies related to winter cyclones.
Available data sets include measurements from the 7 well instrumented aircraft involved in FASTEX (airborne radar data, dropsondes, in-situ measurements, ...), high resolution data from the 7 ASAP ships and the 29 radiosounding stations participating to FASTEX , located all around the North Atlantic Ocean (up to 8 radiosoundings per day during IOPs) , surface and upper-air measurements from the 4 FASTEX ships located in the middle of the North Atlantic Ocean, and many buoys, as well as a large set of satellite imagery and products, both from geostationnary and low orbit satellites.Usual meteorological data are also available. Analysis from the french operational meteorological model ARPEGE are available for each day of the field phase.
The primary point of contact and repository of archived data is the FASTEX Central Data Archive at Meteo-France/CNRM in Toulouse (**www.meteo.fr/cnrm/fastex/**). Other organisations and agencies, such as NCAR/MSS, NOAA/NSSL, UCAR/JOSS in USA, DERA and the Univ. of Reading in UK, INSU/CETP in France, ... maintain subsets of the FASTEX data.

THE FRONTS AND ATLANTIC STORM-TRACK EXPERIMENT (FASTEX): AN OVERVIEW OF THE FIELD PHASE.

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The field phase of the FASTEX project took place in january and february of 1997. The experimental objectives of FASTEX were to *(i)* collect data on the life-cycles of marine cyclones that form and grow over the Atlantic ocean by sampling the same systems at several steps of their evolution *(ii)* document the microphysical and dynamical organization of the related cloud systems *(iii)* conduct the operations necessary to assess the adaptive observation strategy that is meant to improve the predictability of these cyclones.
In terms of data collection, most of these objectives have been reached in the course of the two months. Among the 50 cyclones that formed during that period, 18 have the subject of Intensive Observation Periods. Good trackings have been successfully set up on about half of these occasions. Excellent combination of dropsonde and Doppler radar data exist for about the same amount of cloud systems. There is also about 5 to 7 good cases for adaptive observations. The paper will present an overview of these systems.

HOW DO CYCLONES AFFECT THE LARGE SCALE MEAN HEIGHT OF THE TROPOPAUSE?

M.N. Juckes (Meteorologisches Institut der Universität München)

Cyclones and fronts clearly play a major role in determining the climatological structure of the midlatitude troposphere. A complete theoretical description of this process is, however, lacking. The question is important since it is related to the question of what determines the maximum strength attained by storms. Existing theories, based on linear baroclinic waves, providing speculative answers to the question posed in the title have recently been shown to be inconsistent with general circulation model results. A new concept is presented, based on a modification of convective adjustment by synoptic and planetary scale disturbances. The theory predicts that the vertical change in the saturated equivalent potential temperature should be proportional to the meridional change in temperature across the storm tracks. The prediction is found to be consistent with the annual cycle of these variables.

THE AGEOSTROPHIC CIRCULATION IN BAROCLINIC WAVES GROWING ON FRONTAL TEMPERATURE GRADIENTS

M.N. Juckes (Meteorologisches Institut der Universität München)

The ageostrophic circulation within an analytic, semi-geostrophic, solution for baroclinic waves growing in uniform potential vorticity flow with boundary temperature gradients concentrated in fronts is discussed. The deformation forcing for the ageostrophic circulation vanishes identically in this flow. The circulation arises instead from the along front component of the Q-vectors. This results in a different circulation structure, with vertical motion being fed by along front convergence of the along front ageostrophic wind. This structure is similar to that found in the bent back sector of warm fronts.

STRUCTURE AND EVOLUTION OF THE BOUNDARY LAYER DURING THE FASTEX IOP 18

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The FASTEX IOP 18 (22-23 February 1997) is a cold air cyclogenesis that first developed north of the main baroclinic zone and ended as a classic cyclogenesis, by interaction with this baroclinic zone. In spite of the facts that very early in the life cycle there is a relationship between the upper level potential vorticity anomaly and a surface low, and that low level cloud vortices appear above the Labrador Sea, the rapid development of the IOP18 low triggers only East of Greenland. The presentation is devoted to the description of the boundary layer during IOP 18, using data gathered by aircraft equipped for dropsounding, R/V and ground-based stations performing radiosounding, and ARPEGE operational analyses. Sensitivity of the triggering mechanism to boundary layer processes will be documented. The presentation also mentions links with two other separate talks that investigate the upper level dynamic and a potential vorticity inversion method.

MULTISCALE PROCESSES INVOLVED IN THE MATURE PHASE OF A « BOMB LIKE » DEEPENING

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This paper will present preliminary results for the IOP 12 (09 February 1997) of the FASTEX experiment. Data from airborne Doppler radar observations and from dropsondings done in the multi-scale sampling area of the FASTEX experiment are processed to obtain a composite ensemble of elaborate fields at various scales of motion in a « bomb like » deepening (in either the cloud head, or the cold frontal discontinuity or the so-called bent back warm front) in order to study multi-scale interaction involved in this case. In particular, 3D dynamical, thermodynamical and ageostrophic wind fields and other crucial quantities (PV, Forcing, etc..) are retrieved to scrutinize the following aspects: 1-interaction between the ageostrophic frontal circulation (due to the large scale frontogenetic forcing) the CSI motions and convective motions within rainbands; 2-role of convective motions and CSI areas on the balanced frontal circulation; 3- interaction between the strong gradients of humidity and shear and the ageostrophic circulation. Selected results on these various aspects will be given during the oral presentation

INTERPRETATION OF MID-LATITUDE CYCLOGENESES USING A LINEAR FRAMEWORK.

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The application of classical linear theories of cyclogenesis to real cases is not straightforward. The main problem is the splitting of an atmospheric real state into a "small" perturbation and an "unperturbed" flow. On one hand, linear theories use very idealized basic states and perturbations, and on the other hand, the observed precursors are often finite amplitude anomalies unlike what is assumed in the linear theories.
In spite of these limitations, the IOP 17 of FASTEX may be investigated with a linear approach. The isolation of the perturbation is provided by PV inversion concept. The precursors are removed from the initial conditions of an ARPEGE successful forecast prior to the cyclogenesis. The forecast without the low is considered as the "basic state" varying in space and time. With the tangent linear model of ARPEGE and energetic tools, it is possible to document the linear behaviour of such a real case.

MESOSCALE MODELLING OF A FASTEX CYCLONE: SENSITIVITY TO PHYSICAL PROCESSES DURING EARLY STAGES OF DEVELOPMENT

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One important aspect of the FASTEX program concerns a better understanding of mechanisms involved during early stages of development of extratropical cyclones of North Atlantic. The presentation is relevant to the role of upper-level disturbances and thermodynamical processes (in cloudy regions and boundary layer) during the first phase of a frontal cyclone deepening. The case study is the IOP17 (17-20 Feb 1997), which allows a full set of observations of the low from its formation south of Newfoundland to its mature stage in the Norvegian sea. Numerical simulations are performed with the MESO-NH model, which includes advanced parametrisations for explicit clouds, convection, radiation, turbulence in boundary layer as well as in upper air, and surface processes. The model is initialized by operational ARPEGE analyses, including some FASTEX soundings. Both analysed fields and MESO-NH outputs are processed with the same diagnostic tools, to determine the dynamical and diabatic contributions to ageostrophic circulations. Simulations of the whole life cycle are presented and discussed. A sensitivity study to latent heat release shows a large impact at meso-scales during the development phase. Role of air-sea exchanges is also investigated near the Gulf-Stream current before the trigerring of the cyclone, and in the Labrador sea where boundary layer type clouds are present.

ROLE OF THE ENVIRONMENTAL FLOW AND CONTRIBUTION OF A DECAYING LOW ON THE DEVELOPMENT OF A FASTEX CYCLONE (IOP17)

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The role of the environmental flow on the developpement of a FASTEX cyclone (IOP17) is presented using the domain independant attribution method (Bishop, 1996). A stability study of the surface front is first conducted with calculation of environmental along-front stretching and cross-front frontogenetic component. Results based on operational ARPEGE analyses show low values of stretching rate, with a minimum 6 hours before the triggering of the cyclone. Frontogenetic component is also decreasing until cyclone formation.

Contribution of a decaying surface low moving from the Great Lakes to the oceanic front before the triggering of the cyclone is then investigated by isolating the flow attributable to this "continental" low. This flow induces warm thermal advection on both sides of the surface front diminishing thermal contrast, it represents 20% of the total warm advection. The stability is then discussed again for the surface front embedded in the total flow without the one attributable to the continental low. Larger values of stretching rate and frontogenetic component are found, which shows evidence that the continental low contributes to the IOP17 cyclogenesis by diminishing along-front stretching and frontogenetic effect.

APPLICATION OF EXERGY THEORY TO LOCAL ATMOSPHERIC ENERGETICS: DIAGNOSTICS FOR A FASTEX EVENT.

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The name exergy is used in thermodynamics to denote the available work that can be extracted from a system. A special case of this concept is called available enthalpy in meteorology. The exergy cycle that can be derived from it is a "local" one in that it can be applied to any individual pressure level embedded within any limited area domain.

This cycle is different from the classic one introduced by Lorenz (Tellus, 1955). It is better close to the cycle proposed by Pearce (QJRMS, 1978). It is an exact cycle, without approximation. All the boundary fluxes are taking into account and the vertical exchanges between different levels can be computed.

One case of the FASTEX period have been studied using these exergy diagnostics: it is the law n°38 that crosses the Atlantic from west to east between the 13 and the 16 February 1997. Operational analyzed and forecast data have been used every 6 hours so that the energetic behavior of forecasts can be verified against the energetics of analyzed one. The tendencies are computed starting from a 12 hours centered scheme, the generation and dissipation terms are realistic, they are computed as residuals of the "local" exergy cycle.

All energy tendencies, fluxes, conversion terms, generation terms and dissipation terms will be presented with the help of "time"x"pressure" diagrams, for analyzed and forecasted data (base: day "D" and day "D-1").

DYNAMIC AND THERMODYNAMIC STRUCTURE OF THE MID-LATITUDE CYCLONE OBSERVED ON 19 FEBRUARY 1997 DURING FASTEX

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During FASTEX, coordinated observations were conducted to observe the structure and evolution of mid-latitude cyclones. IOP 17 lasted from 17 till 20 February 1997, a period during which ground-based, ship- and airborne measurements followed a pressure low and the associated perturbed weather, as it propagated and evolved from the eastern US coast to the North Sea. A coordinated mission with the NOAA/P3 equipped with an airborne Doppler meteorological radar and the UKMO/C-130 with dropsonde capability was flown on 19 February from 03 till 12 UTC to document the structure of the precipitating features in the vicinity of the low, and the associated kinematic and thermodynamic characteristics. We will present and discuss preliminary results from the combined analysis of these airborne Doppler and dropsonde data. The deduced characteristics will also be compared with results from numerical models.

USE OF ECMWF SINGULAR VECTORS FOR TARGETING DURING FASTEX

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Calculations of localised singular vectors (SVs) have been performed from the ECMWF/IFS forecasting model for IOPs 9, 11, 12 and 17. For each case-study, two sets of analyses have been prepared: a "control" set consisted of analyses in which all the FASTEX data had been removed from the operational analysis, a "perturbed" set was obtained by adding to the "control" the data from the dropsondes deployed in the region highlighted as sensitive by SVs. Analysis differences have been compared with SV structure at initial time and with "pseudo-inverse" perturbations. Then, re-runs of the model, starting from the two different analyses, have been performed. The impact of the droposonde data on the forecast skill has been assessed on the basis of both subjective (e.g. mean-sea-level pressure forecast errors) and objective (e.g. root-mean-square errors) scores. Experiments of sensitivity to the numbers of dropsondes used have also been performed. Re-runs of the models from perturbed analyses tend to have better objective scores than those starting from the control ones, although synoptic improvements are not always evident on weather charts. Work is also in progress to link SVs to the local atmospheric structure and the time evolution of SVs has been related to that of the basic state: potential vorticity diagnostics have been used to detect preferred regions for SV growth.

A SECONDARY FRONTAL WAVE IN NEGATIVE STRAIN

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Recent work has investigated the role of large scale strain in modulating frontal instability. Diagnoses of strain in model data have confirmed theoretical results, that strain generally suppresses instability and conversely, that instability is greater when the frontogenetic strain becomes weak. In particular, it has been suggested that negative (frontolytic) strain characterises a certain class of frontal wave development. By considering one such case in detail, in which a weak cold front wave develops in a frontolytic environment, it can be seen that it corresponds to the precursor of a triple point low. As such, this suggests a causal mechanism for triple point development, in which a wave, with a weak surface pressure signal, grows rapidly as it moves into the negative strain region (with respect to the cold front) which characterises the frontogenetic warm front. The warm front is a region of potential for instability, and a low develops in the triple point region.

For the case discussed, analysis of the negative strain indicates that its magnitude is large compared to that of the cold front vorticity. In the light of a simple barotropic model, this indicates that the strain is likely to dominate dynamical instability for a part of the development period. As such, this is an indication that the strain may indeed be a key factor in some rapid developments.

TWO-DIMENSIONAL AIRBORNE OZONE MEASUREMENTS DURING FASTEX

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Field measurements in the frame of TOASTE (Transport of Ozone and Stratosphere-Troposphere Exchange) campaigns had shown the evidence of fossile stratospheric layers within the troposphere. This so-called filaments often originate in upper-level frontal activity giving rise to tropopause folds. To test the ability of global models to forecast such layers, to confirm their stratospheric origine and to understand their interaction with the free troposphere, a new TOASTE measurement campaign took place in February 1997, in association with FASTEX. In particular, the Airborne Lidar for Tropospheric Ozone (ALTO) was flown on the French Fokker 27 research aircraft. This way and despite some very cloudy conditions, two-dimensional ozone vertical cross-sections are available. Between the 3rd and the 5th of February, a thin but widespread ozone-rich layer has been sampled. It is likely to originate in a former fold over Canada. This will be developped in a separate talk. During the same campaign, tropopause folds in their development stage have been observed and characterized in both their transverse and longitudinal extensions. Further analyses are now under way using a meteorological mesoscale model (MM5).

DYNAMICS AND STATISTICS OF FORECASTS ERRORS IN A QUASI-GEOSTROPHIC MODEL

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A number of adaptive observational strategies were tested during FASTEX. These strategies make various assumptions about the statistics of errors in analyses and short-range forecasts. We employ a quasi-geostrophic channel model to investigate these statistics as well as the dynamics of small errors. Assuming a perfect model, estimates of error statistics are obtained by averaging over ensembles of forecasts initialized in two ways: In the first, the initial ensemble perturbations have specified (and simple) statistics, and in the second the ensemble consists of analyses from a three-dimensional variational data assimilation scheme, each of which receives independent and imperfect observations from a reference run of the model. We find that the dynamics influence the error statistics on the advective timescale for the flow; typically, this time scale is less than a day in midlatitudes where there is significant baroclinicity.

OVERVIEW OF THE MESOSCALE CIRCULATION AND VORTICITY WITHIN SYSTEMS SAMPLED DURING FASTEX

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One of the main objectives of the FASTEX experiment was the study of the structure of cloud-cyclone systems when they approach western Europe, with particular emphasis on the determination and understanding of dynamical processes involved in the development of secondary cyclones. In this context the systematic sampling of the systems by two aircraft equipped with Doppler radars, namely the US-French radar ELDORA-ASTRAIA, and the NOAA P3-radar both equipped with the French dual-beam antenna, offered a unique opportunity for documenting cloud systems at several scales. In particular the two aircraft regularly performed circular tracks in order to obtain an overview of the mesoscale circulation obtained throughout the sampled systems during each IOP. Vertical profiles of the winds, the terminal fall velocity of the hydrometeors, the divergence, the deformation, and the vertical vorticity were thus obtained, using DAVAD analysis, a new analysis of dual-beam airborne Doppler radar data adapted to circular tracks.
First results of the systematic application of the DAVAD analysis to the ensemble of the circular tracks performed during FASTEX are presented in this paper, along with a synthesis of the results in terms of mesoscale dynamic and thermodynamic description of the observed lows.

NEW OBSERVATIONAL PROOFS FOR SHORT-THERM VARIATIONS OF FORMATIONS OF LOWER TROPOSPHERE ASSIGNED TO GREAT SUNSPOTS ,AS CONTRIBUTIONS TO THE CYCLOGENESIS

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In our previous papers (EGS Gen.Ass.1994-1997 and 17th Int.Conf.on Carpathian Meteorology 1996) we are coming to the conclusion that between the time of crossing the solar Central Meridian by so called "correlational" sunspots and the time of appearance of meteorological cyclones in the Carpathian Basin exists one very close connexion,one very strong correlation.In this paper we refer to the solar and meteorological events between 7-16 SEP 1997.Before 23-24 AUG yet not a single sunspot showed,but after these data the number and the dimension of sunspots has been grown considerable,in conformity with the Mt.Wilson MWSI and MSPI index.The Wolf-number in 09 SEP was 125 .In 07 SEP appeared on eastern-margine a "correlational" sunspot with one very deep umbra,having a diameter over 20,000 km,preserving its characteristic during pass of solar-disc.This sunspot crossed the Central Meridian in 13 SEP ,the MWSI being around of 0,6 and in 14 SEP (delay only one day) the polar-cyclone appeared in Salonta (near border between Hungary and Roumania) as one very good defined cold-front with Cirrocumulus lenticularis,rain-clouds,after a sudden shower a running rainfall (11.9 mm),very strong northerly-wind,negative temperature gradient (-15 C),meridionale stream-field transforming in one zonale stream-field.

UPSTREAM BAROCLINIC DEVELOPMENT OF SECONDARY FRONTAL-WAVE CYCLONES: IDEALIZED AND OBSERVED

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Numerical simulations of idealized cyclones with a primitive equation model in an extended f-plane channel show the formation of downstream and upstream cyclones that emanate from an initial, finite-amplitude, upper-level disturbance. Downstream synoptic-scale cyclones first appear in the vicinity of the tropopause and develop downward to the surface during their life cycle. In contrast, smaller, intermediate-scale, frontal-wave cyclones form upstream from the initially perturbed cyclone, first appearing as amplifying waves at the end of the trailing surface cold front of the initially perturbed cyclone, followed by an upward development to the tropopause. Differences in cyclone evolution, i.e., downstream "top down" versus "bottom up" development, are presented as idealized analogs of the Petterssen and Smebye (1971) "type B" versus "type A" cyclogenesis, respectively. Observations from the Fronts and Atlantic Storm-Track Experiment (FASTEX) illustrate examples of two North Atlantic cyclone developments that formed along the trailing cold front of a preceding primary rapidly developing cyclone. These secondary upstream developments were simulated with the NCAR/Penn State multiscale prediction model. It is proposed that the Norwegian cyclone family conceptual model with its upstream frontal-wave developments that form and trail behind the primary occluding cyclone is in agreement with the theoretical concepts of secondary upstream baroclinic development.

ENSEMBLE–BASED TARGETED OBSERVATIONS DURING FASTEX

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Targeted observations were adaptively taken in upstream sensitive areas during the FASTEX field experiments in order to improve the initial conditions for forecasts of frontal waves or mesoscale cyclones developing downstream. We evaluate the performance of the Ensemble Transform (ET) technique, which is one of several targeting methods used in real time during FASTEX, for seven Intensive Observing Periods. In the ET method an ensemble of forecasts, which is assumed to represent analysis and forecast uncertainty under standard observational conditions, is transformed to represent uncertainties with an observational network augmented by extra targeted observations at any selected location. The ensemble–based targeting methodology, using the NCEP operational global ensemble, was found succesful in the following sense. (1) The ensemble spread in the standard ensemble is a good indicator of expected errors in the first guess forecast fields. (2) The ET technique can identify sensitive areas that affect preselected features developing downstream most at a later time. (3) The Amplification of Ensemble Perturbations (AEP) from the sensitive area to the verification area is an excellent indicator for the impact the real observations have on the control forecast. (4) AEP is highly correlated with the forecast improvement the targeted data brought about. The ET results suggest that targeting observations is a practically feasible way of improving forecast accuracy for preselected features in a complex flow. To insure that targeted observations have the maximum possible positive impact (1) targeted data should be collected only for cases with high AEP, (2) for possibly large areas, and (3) be assimilated using flow dependent covariance information.

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The extratropical transformation of Atlantic hurricanes in 1995

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The Atlantic hurricane season of 1995 was extraordinarily active not only in terms of the number of hurricanes but also in terms of the number of storms which transformed into extratropical cyclones. According to the National Hurricane Center 7 tropical cyclones underwent extratropical transformation in the North Atlantic and 2transformed over the continental US. At least 2 of the transformed storms affected western Europe. In fact Iris had a lower central pressure as an extratropical storm near the UK than as a hurricane. A further 3 tropical cyclones moved northwards of 35N but did not transform. This paper presents a synoptic overview of extratropical transformationof hurricanes Iris and Felix which occurred in the 1995 season using analyses from the UK Meteorological Office. Standard synoptic variables such as pressure and temperature along with derived quantities such as potential vorticity are used. The relationship of the tropical cyclone to upper level troughs, lower level baroclinic zones and surface low pressure systems is studied. Information:

SUB-SYNOPTIC SCALE INSTABILITY ALONG THE JET STREAM

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We have investigated the stability of a realistic model of the mid-latitude jet stream for both synoptic and sub-synoptic scale disturbances in the primitive equations system and subject to the anelastic approximation. Nonseparable linear analysis of the stability of the two dimensional balanced jet reveals the existence of three primary modes of instability, respectively the Charney-Eady mode, a shallow sub-synoptic mode, and a mode that is focused on the tropopause. The same three modes of instability are also found in a simpler one dimensional model of tropospheric structure. The existence of the first two modes has been further confirmed in a series of three dimensional nonlinear simulations initialized with the same basic state flow and superimposed noise generated entirely by numerical truncation errors. Furthermore, in the evolution of the sub-synoptic scale mode we have been able to isolate a pairing interaction through which the initial shallow disturbance dramatically deepens as its wavelength doubles. This would appear to represent a new mode of development.

OA14 Parametrizations in large scale atmospheric models

Convener: Viterbo, P.

01 Intercomparison and validation of the ocean-atmosphere flux fields

Convener: Gulev, S.
Co-Convener: Taylor, P.K.

Sponsorship:

ON THE HISTORY OF OCEAN WAVES IN THE NORTH SEA

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Ocean waves evolve from wind fields of present and past times. The waves spread out from their generation region until they reach a coast where they break. Time series of wave data at a position describe the temporal evolution but the region of generation of the incoming swell waves can not be reconstructed. A numerical scheme is presented to determine the generation region by means of the spectral wave age. The spectral wave age is a measure of the time interval which has past since the spectral wave component was generated. The scheme was formerly developed for wave data assimilation. Now, the scheme is used to estimate the impact on the wave climate in coastal regions from remotely occurring storminess. In addition, pattern of wind fields and wave fields which share maximal correlation are determined from Canonical Correlation Analysis (CCA). The correlation function which is determined from CCA varying the lag of time between the fields has a secondary maximum. This supports further that a significant fraction of wave energy is of nonlocal origin. Results are shown for waves propagating into the North Sea. Typical generation regions of the waves in the coastal regions are determined and possible coastal wave climate changes through wind climate changes in the generation region are discussed.

FORCING OCEAN GENERAL CIRCULATION MODELS WITH AIR-SEA FLUX FIELDS

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Solar radiation and air-sea exchanges of heat are responsible for temperature variations in the surface ocean and the lower atmosphere. Due to the larger heat capacity of the ocean, the time evolution of the ocean temperature is significantly slower. Thus, the ocean is the slow component of the coupled ocean-atmosphere system, and the paradox of forcing an ocean model with a prescribed atmosphere is that the slow component is forced by the fast one. Therefore, it is not possible to force an ocean general circulation model without some kind of a parameterization to account for the feedback to the atmosphere. An ideal situation would be to use an atmospheric model coupled to the ocean model, but it is not reasonable at present, for many reasons, to use coupled models for every ocean modelling application. The paper will discuss parameterizations of the ocean forcing function based upon model dependent flux corrections which objectives are to account for the feedback to the atmosphere and for uncertainties in air-sea flux estimates. The paper will aslo discuss the notion of geophysical consistency of the various components of the atmospheric forcing function, which is so important to ocean modelling. The presentation will make use of a monthly mean climatology of air-sea fluxes obtained from the 15 year re-analysis performed at ECMWF. Results from recent eddy-resolving simulations of the North Atlantic will be used to discuss the impact, interpretation, and short-coming of the flux correction term.

AIR-SEA FLUX AND PRECIPITATION MEASUREMENTS IN THE LABRADOR SEA DURING FEBRUARY AND MARCH 1997

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Turbulent fluxes of sensible heat and momentum, which influence convection events in the ocean, were measured during the Labrador Sea Convection Experiment on the RV KNORR in winter 1997. The turbulent fluxes of momentum were estimated using the dissipation method, while the eddy correlation method was used to get sensible heat fluxes. Conditions were highly convective during the whole period with air-sea temperature differences of up to about -15K, and wind speeds were usually higher than 10m/s. Measured fluxes were compared to fluxes calculated by different boundary layer parameterizations. Since the thermohaline circulation in the ocean is also influenced by precipitation due to changes in the surface salinity, precipitation too was measured by an optical disdrometer. These precipitation rates were compared with estimates of precipitation from synoptic weather observations by using an empirical relationship.

THE SEA SURFACE FLUX DATASET COLLECTED DURING THE CATCH/FASTEX EXPERIMENT

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The CATCH experiment was part of the FASTEX experiment during January and February 1997. An important ocean-atmospheric data set was collected on board of the N/O Le Suroît. The ship was located along the storm track and moved across the oceanic front system associated with the North Atlantic current. The main characteristics of this data set is the strong heterogeneity of atmospheric and oceanic conditions with periods of winds stronger than 20m/s, strong sea surface temperature gradients and strong instability. Several storms were sampled during the cruise and classified in term of large scale weather conditions and local atmospheric measurement. Different bulk flux parameterizations were then applied to this data set to derive the turbulent fluxes in order to test their discrepancy by strong winds. These turbulent fluxes indicate that the flux are generally very weak in warm sectors despite the presence of the frontal jet and sharply increase up the $800 Wm^{-2}$ in cold sectors because of sea surface and atmospheric temperature difference reaching values up to $10°C$.

FOAM COVERAGE AND SKINEFFECT OF THE OCEAN FROM SATELLITE DATA

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The foam cover of the ocean and the effect of the cold ocean skin have a strong impact on the gas exchange between ocean and atmosphere. The skineffect describes the temperature difference between the cold skin and deeper layers of the ocean. Both parameters can be estimated with global coverage and sufficient accuracy using spaceborne infrared- and microwave-radiometers. The oceanic foam coverage can be directly retrieved from measurements of the Special Sensor Microwave / Imager, while the skineffect is estimated from the energy fluxes at the air-sea interface. These energy fluxes are calculated with a bulk-parametrization from the relevant atmospheric and oceanic parameters, which are derived from satellite data.
For the time period July 1987 to January 1989 global fields of the skineffect and foam coverage have been calculated. The monthly mean of the skineffekt for night situations vary between 0K and 0.45 K. Because of the heating of the oceanic surface layer due to the insolation, the skineffect for daytime is reduced. Global monthly fields of the satellite-derived foam cover indicate that values with more than 2% only occur polewards of 40° in both hemispheres and a maximum of about 4% in the respective winter.

IMPACT OF THE HORIZONTAL GRID IN AN ATMOSPHERIC MODEL

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A preliminary test before coupling together atmospheric and oceanic general circulation models is the complete validation of the atmospheric and oceanic components and especially of the flux fields at the interface. Indeed, if the fluxes computed by the atmospheric model contain important errors, the oceanic model in coupled mode will drift away from observed values.

In this study, we have used the atmospheric model (LMDZ) built at the 'Laboratoire de Météorologie Dynamique' of the CNRS (Paris). A characteristic of this model is its ability to run with different horizontal grids. We have performed two atmospheric runs in forced mode with a regular grid or a sine of latitude grid in order to quantify the impact of the horizontal resolution on the model results. The resolution has 72 points in longitude and 45 points in latitude. The fluxes at the interface have been compared between the two runs and also with the observations. We have paid a particular attention to the polar regions and analyzed the atmospheric states over these regions.

UPPER OCEAN HEAT AND SALT BALANCES IN THE WESTERN EQUATORIAL PACIFIC DURING TOGA COARE

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The upper ocean heat and salt balances in the western equatorial Pacific warm pool during the Tropical Ocean Global Atmosphere (TOGA) Coupled Ocean-Atmosphere Response Experiment (COARE) were determined. Horizontal advection terms in the budget calculations are estimated using the R/V Wecoma repeat hydrographic survey data within a 130 km x 130 km region from three cruises during the 4-month-long Intensive Observation Period of COARE. Ocean microstructure measurements from the R/V Moana Wave were used to estimate the turbulent mixing at the bottom of the control volumes. The (cruise mean) upper ocean heat budget is balanced within 10 Wm-2 of the air-sea flux observations during the three cruises. The air-sea freshwater flux is predicted from the upper ocean salt budget, and the derived precipitation values fall within the range of observations. During the strong westerly wind burst of December 1992, the salt budget fields a rainrate of about 15 mm d-1, which is within about 20% of the rain guage observations composited from several nearby platforms. Advection terms are important in both the heat and salt balances. Meridional advection dominates over the zonal and vertical advections, acting to decrease the surface temperature and increase the surface salinity. The total heat flux into the thermocline is estimated to be more than 30 Wm-2. Both the diapycnal mixing and diapycnal advection terms are also important in the salt budget during the westerly wind burst.

THE NORTH ATLANTIC OCEAN-ATMOSPHERE HEAT AND FRESH WATER FLUX VARIABILITY DERIVED FROM OCEANOGRAPHIC REPEATED SECTIONS DATA

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Repeated transatlantic hydrographic sections at 48°, 36° and 24° N were chosen for direct heat and fresh water air-sea flux evaluations. The coordinated strengthening and weakening of the meridional heat transport at 36°N and 48°N were revealed while changes at 24°N were negligible. The divergences of the meridional heat fluxes between the repeated latitudinal sections are marked by high energy flux to the atmosphere between 36°N and 48°N in the early 1980s and low air-sea exchange between 24°N and 36°N, while in 1950s and 1990s the situation was reversed and the heat exchange was much more higher in the southern part of the mid-latitudes. Despite of high uncertainties, the sign of the surface fresh water flux maintains the principal features of the heat flux divergence variations: the meaningful excess of evaporation in 1980s between 36°N and 48°N and the same situation between 24°N and 36°N in 1950s and 1990s.

AN OGCM SIMULATION FORCED BY DAILY ECMWF SURFACE FLUXES: HOW TO DEDUCE OCEANIC HEAT FLUXES FROM SEA LEVEL VARIATIONS ?

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Daily surface fluxes of heat and wind stress calculated from the recent ECMWF reanalysis for the years 1989 to 1993 are used to drive a high resolution primitive equation model over the North Atlantic ocean. The simulation is compared with the observed sea surface temperature (SST) and analyzed in terms of deficiency of the model and/or the forcing condition. Agreement between model and data is satisfactory during summer over the eastern part of the basin (SST error on the order of 0,5°C), whereas discrepancies increase during winter, exceeding 1,5°C in that area and 4°C in the Gulf Stream region.
The heat budget of the upper ocean is then studied, revealing that in the north-eastern part of the Atlantic and on scales on the order of 1000km, the change in local heat content balances the surface heat fluxes, the advection being negligible. Since the steric height variation results mainly from the heat content change, the seasonal cycle of surface heat flux can be retrieved directly from sea level variations with an accuracy of about $20 W/m^2$. Using the sea level anomaly from Topex/Poseidon altimeter, we then estimate seasonal oceanic heat fluxes for the years 1993 to 1997 and compare them with heat fluxes from the NCEP reanalysis.

IMPACT OF SURFACE LAYER HEIGHT CONSIDERATION ON AIR-SEA FLUXES FOR THE NORTH ATLANTIC

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The log wind profile typically used in adjusting for differences in anemometer heights between ships is strictly valid only within the surface (constant flux) layer. There can be strong shear above the surface layer that is not accounted for by the log profile. Under stable conditions, the average ship-based anemometer extends above the surface layer and into this region of strong shear, introducing some error into the height corrected winds. The height of the surface layer is incorporated into the anemometer height correction process through a simplified one dimensional atmospheric boundary layer model. The mean magnitude of corrections to wind stress and latent heat flux fields resulting from surface layer height consideration are compared to those due to correction of both visual wind estimates and basic anemometer height adjustment. Despite affecting fewer observations than either Beaufort scale or basic anemometer height adjustments, surface layer height consideration yields mean corrections of similar magnitude to these more common adjustments. The flux fields for the North Atlantic Ocean are calculated, and the impacts of these corrections on ocean circulation characteristics explored.

SATELLITE-DERIVED OCEAN SURFACE ROUGHNESS AND ITS USE IN REGIONAL WIND STRESS DETERMINATION

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Single frequency altimeters routinely produce global ocean wind speed estimates. However, uncertainty in this product remains in large part because the relative impact of long and short ocean waves on backscatter has not been well established. Recently, measurements of the TOPEX dual-frequency altimeter were used to estimate a surface wind stress that is free from long wave contamination, at least for moderate to high winds. As an alternative, we also proposed a new altimeter-derived parameter characterizing sea surface roughness of small scale, zw. It was shown that altimeter-derived surface roughness seems to be strongly correlated with aerodynamic roughness length, zo. But, as there was no independent estimation of wind speed in this study, this remained untested. Here, using wind model, satellite scatterometer and altimeter data, we analyze this relation between zw, zo and surface wind to show the utility of the altimeter product. In particular, this zw parameter is estimated for the Tropical Pacific and Azores to examine regional and temporal variation of wind stress. Results are compared and contrasted with availeble stress fields.

DROPSIZE DISTRIBUTIONS OF MARINE TROPICAL PRECIPITATION FROM DIFFERENT CLIMATIC REGIONS

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The large scale circulation of the world oceans is not only driven by the wind but also by density gradients. The contribution of precipitation to the total fresh water input into the oceans, however, is practically not known. Nowadays space borne remote sensing techniques are used to estimate global precipitation. These methods, however, use algorithms based on the assumption of simple logarithmic dropsize distributions (Marshall and Palmer, 1948) at the ground. During 1997 in situ measurements of precipitation have been performed on different research vessels operating between 7 and 60 degree northern latitude. A total of about 15 000 dropsize distributions were recorded and analyzed with respect to their curvature, rainrate, liquid water content and radar reflectivity. In order to overcome the problems of precipitation measurements on moving ships the IfM optical disdrometer (ODM 470) was used. This novell disdrometer records dropsize distributions with a resolution of 0.05 *mm*. Both the dropsize distributions of low and high latitudes show large variability in curvature and rainrate. Knowledge of more realistic marine precipitation characteristics will help to improve the remote sensing of precipitation.

USING TENDENCY ERRORS TO OPTIMIZE HORIZONTAL DIFFUSION IN A GENERAL CIRCULATION MODEL

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In this study high resolution simulations are used to tune the horizontal diffusion in lower resolution climate simulations. Such a diffusion is needed to parameterize the dynamical effects of un-resolved wave-wave interactions or in other terms the energy and enstrophy cascades. We first use a simple four dimensional data assimilation (nudging) to assimilate high resolution data into a T42/L31 version of the ARPEGE/IFS climate model. In this way the forcing errors can be monitored. A certain fraction of the forcing errors can be attributed to simple damping of individual spectral coefficients which is the most common way to parameterize horizontal diffusion in spectral GCMs. This damping is then considered an entirely empirical tuning of the horizontal diffusion. When the new horizontal diffusion finally is used in long climate simulations with ARPEGE, it is seen that the energy spectra are in better agreement with observed spectra. Furthermore, the general circulation and and the level of low-frequent variability is somewhat improved. The high resolution data which are used for the tuning include both ERA-data and data from a T106/L31 simulation with the ARPEGE model.

INTERCOMPARISON OF THE REGIONAL HEAT BALANCES FROM HYDROGRAPHIC DATA AND VOS OBSERVATIONS FOR THE NORTH ATLANTIC MID LATITUDES

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Oceanographical estimates from the cross-Atlantic crossections at 25N, 36N, and 48N allow to compute divergences of the heat for two latitudinal belts in the North Atlantic mid latitudes. These estimates were obtained for the three periods - 1957-1959, 1981-1982, and 1992-1993 and show quite a large change of the imbalances. Oceanographical imbalances estimates which are assumed to be balanced by the sea-air heat flux, are compared to the fluxes evaluated from the individual COADS reports for these three periods. Different parameterizational schemes and correction procedures were used to arrive to the oceanographical estimates. Nevertheless, with no one combination of parameterizations we were not successful to fit (with the accuracy of uncertainties) to all six (three periods by two latitudinal belts) hydrologial estimates of imbalances. There is a better agreement for the latitudinal belt 36-48N. With respect to the time, the largest disagreement was found for the early 1980s. There was somewhat better progress with the description of tendencies in the divergincies, although not very much progress. The question remains, whether oceanographical adjustment of the sea-air fluxes is a reasonable exercise.

EVAPORATION AT THE SURFACE OF THE BALTIC SEA

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BALTEX is aiming at the exploration and modelling of energy and water budgets of the entire water catchment area of the Baltic Sea. The Baltic Sea covers about 20 % of the BALTEX region, and, at present, it is not precisely known whether precipitation minus evaporation over the Baltic Sea, even on an annual basis, is negative or positive. COADS ship observations from the period 1964 to 1995 have been used to calculate climatological estimates of evaporation for different sub-basins of the Baltic Sea using bulk parameterisations. Evaporation is corrected in the presence of sea-ice. Evaporation at the Baltic Proper shows a prominent annual cycle. Mean monthly values are lowest in May and highest during September to November. Individual monthly averages for sub-basins of the Baltic Proper range from near zero to more than 100 mm/month. Individual observations show extreme values exceeding 20 mm/day (equivalent to a latent heat flux of more than 600 W/m^2). The sensitivity of these estimates to both different parameterisation schemes and corrections of known observational biases is discussed. In particular implications of a new Beaufort scale and corrections to SST and airtemperature according to Kent et al. (1993) are presented. The annual cycle of evaporation shows fair agreement with that taken from a 10-years run of the MPI climate model ECHAM4-T106.

A NEW SATELLITE METHOD TO OBTAIN OCEAN LATENT AND SENSIBLE HEAT FLUXES

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The exchange of energy, momentum and mass between the air-sea interface has to be consistently monitored in order to describe the natural climate variability. Long records of latent and sensible heat fluxes estimated from in-situ observations have been mainly limited to voluntary observing ships and moored buoys, and these lack adequate spatial and temporal coverage. Other sources of data such as satellite retrievals and global fields from reanalysis projects include comprehensive temporal and spatial resolution and provide additional information that can complement in-situ observations. This paper presents a new satellite method to compute ocean latent and sensible heat fluxes. The method uses a similarity theory model, surface wind speeds and total precipitable water from the Special Sensor Microwave Imager (SSM/I) and SST from NCEP reanalysis. The innovative aspect of the new methodology is the estimation of surface specific humidity and air temperature. These are estimated from SSM/I total precipitable water and NCEP SST reanalysis using an artificial neural network trained to high quality surface marine data. The data record extends from January 1988 through October 1997. This paper will show a comparison of latent and sensible heat fluxes from NCEP/NCAR reanalysis, surface marine data and satellite estimates.

INTERCOMPARISON OF OCEAN ATMOSPHERE FLUXES FROM ATMOSPHERIC AND OCEANIC MESOSCALE SIMULATIONS

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The **SEMAPHORE** experiment was conducted in the Azores-Madeira area from June to November 1993 and was devoted to the study of air-sea interactions at the mesoscale. The extended dataset collected during the IOP allows the initialization of mesoscale oceanic and atmospheric models.
A preliminary study with 1D and 2D idealized atmospheric simulations has shown the impact of a SST front on the atmospheric boundary layer. Symmetrically, 3D oceanic simulations on the SEMAPHORE area revealed a strong response of the oceanic mixed layer, specially during the 29-30 Oct 1993 storm event. Consequently, this period was chosen to focus on the coupled physical processes at the ocean-atmosphere interface. Two simulations have been performed: one with the non-hydrostatic mesoscale atmospheric model Meso-NH of the CNRM and LA laboratories and one with the mesoscale version of OPA, the primitive equation oceanic model developed at the LODYC (Laboratoire d'Océanographie Dynamique et de Climatologie, Paris). These runs show the ability of both the atmospheric and the oceanic models to reproduce most of the mesoscale features observed during the storm event. The surface fluxes of the two simulations will be compared in order to investigate the physical processes that may prove significant when the two models are coupled.

HOAPS: A SATELLITE-DERIVED WATER BALANCE CLIMATOLOGY

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Global water balance estimates suffer often from the lack of data over remote ocean areas especially in the southern hemisphere. Polar orbiting satellites like the Special Sensor Microwave/Imager (SSM/I) and the Advanced Very High Resolution Radiometer (AVHRR) provide an almost global coverage within a few days. Hence, it is meaningful to derive a climatology of ocean-atmosphere evaporation, rainfall, and water balance with recently developed methods from SSM/I and AVHRR data. Whereas the rainfall is retrieved directly from SSM/I data, evaporation has been parameterized from satellite-derived atmospheric humidity, wind speed, and sea-surface temperature using a bulk approach. All retrieval methods were validated in comprehensive comparison studies with various in situ measurements.

In this study the described methods are applied to satellite data during a 10 year time period, covering 1987-1996. The satellite-derived evaporation, rainfall, and water balance are sampled onto a global grid with three different spatial resolutions (0.5°, 1.0°, 2.5°) and averaged for three different time resolutions (day, pentad, month). The monthly, seasonal, and annual variability of the water balance on a global scale will be presented together with examples for processes like monsoon and El Niño events with high temporal and spatial resolution.

COMPARISON OF SURFACE HUMIDITY AND AIR TEMPERATURE ABOVE THEOCEANS FROM NCEP AND COADS DATA SETS

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Monthly means of the surface specific humidity (qa) und air temperature (Ta) from NCEP-Reanalysis and COADS data set have been compared above the oceans (700N-300S) for the period 1982-1993 (144 months). The results show that: on average (700N-300S) the COADS-qa is lower than the NCEP-qa by about 0.5 g/kg, the qa differences generally decrease in the course of time, and that: the COADS-Ta is generally higher by about 0.40C, the Ta differences increase in the course of time, the Ta differences in subtropical areas and in mid-latitudes north of the equator dependent on the season, however opposite to the qa differences (higher in summer, lower in winter). Further, the spatial patterns of the Ta and qa from COADS as well as from NCEP-Reanalysis are examined with regard to their coherency. Based on the evaluated exponential relationships between the monthly means of the Ta and qa (seperatly for COADS and NCEP), the residual fields of the observed and computed qa are analysed. Whilst the mean residual fields from the COADS coinside well with the large-scale circulation patterns, the corresponding NCEP fields are indistinct. The evaluated relationship between the Ta and qa from COADS for the period 1982-1993 is applied to an assessment of the monthly means of qa for the period 1951-1993 and the predicted qa fields have been compared with the observed qa fields by means of pattern regressions.

COMPARISON OF SURFACE METEOROLOGICAL DATA AND FLUX FIELDS WITH IN-SITU MEASUREMENTS OVER THE LABRADOR SEA DURING WINTER

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The Labrador Sea is an area where intense air-sea interaction and ocean thermohaline deep convection is present during winter. Dense water which is formed by the ocean heat loss and increasing surface salinity is important for the renewal of deep and bottom waters and the ocean circulation system. Typical is an instable boundary layer over the Labrador Sea during winter caused by continental cold air advection in combination with strong northwesterly winds. The aim of this study is to investigate the quality of surface data fields with the focus on air temperature, humidity, sea surface temperature, wind speed and the turbulent fluxes. In situ measurements for this comparison were made on the RV Knorr during the Labrador Sea Deep Convection Experiment in February and March 1997. Sensible and latent heat fluxes were nearly 300 W/sqm on average during the cruise using ship measurements and bulk formula for calculation. The used data fields are from the NCEP Reanalyis Model, the mesoscale model REMO and remotely sensed parameters. In data sparse regions like the Labrador Sea additional informations are useful. Thus surface wind speed and latent heat flux are considered which are derived from microwave brightness temperatures measured with the Special Sensor Microwave/Imager(SSM/I).

RETRIVAL OF THE OPTICAL PROPERTIES OF THE BALTIC AEROSOLS - COMPARISON OF TWO METHODS

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Results of two methods of estimation of aerosol optical properties over the Baltic sea are compared. The direct (exact) method is based on measurements of the direct component of irradiance at the sea surface in 8 spectral bands (412, 443, 490, 510, 555, 670, 765, 865 nm - the same as SeaWiFS). In the indirect method, Baltic aerosols are assumed to be a mixture of model aerosol types with strictly defined optical properties, i.e. maritime, rural and urban types. Their proportion in the Baltic aerosol is retrived from broadband spectral global irradiance measurements (VIS, IR) using radiative transfer parametrisation. Simultaneous measurements of the spectral global irradiance and its direct component taken on cloudless days at the South Baltic are applied to the comparison.

WIND OVER WAVES COUPLING

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Wind over waves coupling models allow to relate the sea drag to the properties of the sea surface and peculiarities of momentum exchange at the sea surface. The drag coefficient can be then directly calculated from the wind speed and the sea state, expressed in terms of the wind wave spectrum. In the presence of sea spray, ejected into the atmosphere by breaking waves, the sensible heat and humidity fluxes above the sea depend on the momentum flux, and peculiarities of sea spray distribution above waves. A one-dimensional wind over waves coupling model is used to assess the wind speed dependence of momentum, heat, and humidity exchange coefficients. The model is viewed as a higher order parameterization of the marine surface boundary layer compared to the bulk parameterization. A rôle of short wind waves in forming the momentum flux to the sea is explained. The difference in exchange mechanism of momentum and heat is underlined. It is shown that the impact of sea spray on heat and humidity fluxes can be significant for a wind speed of about 25 m/s and above.

AIR-SEA INTERACTION AND THE WEDDELL POLYNYA

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During the austral winters of 1974-1976, there existed within the ice-covered Weddell Sea a region of approximately 350,000 km2 that remained ice free. The absence of the insulating sea ice cover exposed the relatively warm surface waters of the Weddell Sea to the cold and very dry antarctic atmosphere. The ensuing intense air-sea interaction lead to vigourous convection in the ocean that resulted in the formation of a significant amount of Antarctic Bottom Water, the water mass that dominates the lowest 2 km of the world ocean. Remarkably little is known about the intense air-sea interaction that was associated with the polynya. This has resulted in a considerable amount of uncertainty regarding certain important aspects of the processes of ocean convection and Antarctic Bottom Water formation as they occurred within the polynya. In this presentation, we will make use of the NCEP/NCAR reanalyses to provide a first view of the spatial and temporal variability in the air-sea interaction that occurred as a result of the existence of the polynya.

VALIDATION OF FOAM MODEL FLUXES USING DATA FROM THE VIVALDI-96 CRUISE IN THE NORTHEAST ATLANTIC.

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The aim of this work was to test the air–sea heat fluxes produced by the FOAM (Fine resolution Ocean–Atmosphere Model) of the U.K. Meteorological Office (UKMO) by comparing them with in-situ fluxes observed during the U.K. Vivaldi cruise in the northeast Atlantic during Autumn 1996, and heat content changes in the upper 200 m of the ocean observed during the same cruise. The FOAM fluxes generally agreed within 30 W m^{-2} with the ship's fluxes even though the net flux varied between +5 and -315 W m^{-2}.

The FOAM fluxes were then applied to a mixed layer model run at four crossing points along the cruise track where observed heat content changes were calculable. The model was also driven using estimates of the geostrophic heat advection derived from the cruise's CTD data, and estimates of Ekman advection and pumping derived using ECMWF wind stress data. The model showed that the air–sea heat flux dominated the heat budget at all of the crossing points. However, the difference between the observed and predicted heat content change was 300 W m^{-2} at one of the sites, and over 100 W m^{-2} at two of the others. Since the FOAM fluxes compared well with the ship's fluxes, but not the observed heat content changes the implication was that heat advection played a larger rôle in the heat budget than predicted by the model.

USE OF SATELLITE FLUXES FOR OCEAN MODELING

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Uncertainties in the surface wind field have long been recognized as a major limitation in the interpretation of results obtained by oceanic circulation models. Surface winds over the global oceans are measured by scatterometry since ERS-1 launch in August 1991 by the European Space Agency and now with the follow-on ERS-2 launched in January 1995. More than six years of mean weekly surface winds were processed onto a 1o square grid at "Institut Francais de Recherche pour l'Exploitation de la Mer" (IFREMER). These winds are validated by comparison with various buoys arrays, showing a good agreement. In order to further evaluate this new wind field, the three-dimensional ocean model OPA7 developed at LODYC has been forced over the tropical oceans by the ERS derived wind stress fields and by fields from the atmospheric model Arpege/Climat for comparison purpose. Selected ocean parameters have been defined in order to validate the ocean model results with measurements of the TAO b!uoys and with the TOPEX-Poseidon altimeter measurements in the Pacific ocean. It shows that the ability of the model to describe the short scale (a few weeks to a few years) oceanic variability is greatly enhanced in the case where the satellite surface forcing is used. It appears also that using solar and fresh water fluxes from the Arpege/Climat model, non coherent with the ERS-derived heat and momentum fluxes, induces biases in the mean ocean state. In the work presented here, we discuss mainly the impact on the oceanic simulation of the forcing fluxes coherency.

THE IMPACT OF AIRFLOW DISTORTION ON IN-SITU METEOROLOGICAL WIND SPEED MEASUREMENTS

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Wind speed measurements obtained from ships are subject to systematic errors caused by the distortion of the air flow around the ships hull and superstructure, an effect which is well known qualitatively. The effects of flow distortion can be significant even in the case of anemometers located in well-exposed sites on research ships. It is therefore necessary to correct such ship-based measurements for these effects if accurate wind speed or surface flux estimates are to be obtained. In the case of merchant ship data, the errors in anemometer-derived wind speeds are likely to be more severely affected.

In this study, we discuss the use of a commercial Computational Fluid Dynamics (CFD) code which was used to simulate the flow air around various ships. This is believed to be the first fully 3-dimensional model to be used for this purpose. A range of results for different research ships will be shown to illustrate 1) the magnitude of the flow distortion, and 2) the sensitivity of the flow distortion to the ship's orientation to the wind. Initial results from models of the air flow around merchant ships will also be shown.

OBSERVATIONS OF ROLL VORTICES DURING AN EXTREME COLD AIR OUTBREAK OVER THE LABRADOR SEA.

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Observational data from two research aircraft flights are presented. The flights were planned to investigate the air-sea interaction associated with an extreme cold air outbreak that occurred after the passage of a synoptic-scale low pressure system over the Labrador Sea during February 1997. Both high-level dropsonde and low-level flight level data were collected. The objectives were twofold: to map out the structure of the ubiquitous roll vortices, often illustrated by 'cloud streets' in satellite imagery; and to estimate the sensible and latent heat fluxes between the ocean and atmosphere during this event. The latter was achieved by a budget analysis of the Lagrangian flight level data. The flights were part of the Labrador Sea Deep Convection Experiment, investigating deep oceanic convection, and planned to overpass a research vessel in the area. Preliminary results suggest very large surface sensible fluxes (over 500 Wm^{-2}) and smaller latent heat fluxes (50-100 Wm^{-2}) occurred just off the ice-edge.

AIR-SEA-ICE INTERACTION IN POLAR REGIONS ON THE BASE OF EXPERIMENTAL DATA

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The present work is devoted to a detail analysis of the various aspects of air-sea interaction in the polar regions. Much attention has been paid to the estimation of bulk transfer coefficients for sensible, latent heat and momentum over snow, different ice types and over leads end polynyas. These coefficients have been measured rarely, but are necessary for accurately modeling the surface energy budget. The data of AIDJEX, POLEX, Polex-GARP and other many-year data of Russian and foreign research expedition are used. The suitable methods of the measurements and calculations of the turbulent fluxes for the polar conditions are chosen. The data about surface roughness, bulk aerodynamic transfer coefficients, heat budget are systematized in dependence on wind speed and type of surface. The turbulent transfer of heat from leads and polynyas in winter is one of the largest terms in polar heat budget, therefore the peculiarities of the turbulent exchange over its are taken into consideration.

A critical analysis of the empirical formulae for estimating the radiative fluxes over the Western Mediterranean Sea

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Direct measurements of solar radiation, atmospheric radiation, sea surface temperature and meteorological parameters were carried out during 13 cruises in the Western Mediterranean Sea in the years 1989-1997. These data constitute the more large experimental radiation data set available for this basin. The data were used to carry out a comparison between direct measurements and the predictions obtained by the most widely used radiative bulk formulae. The results show a general disagreement between measured and estimated fluxes for both solar radiation and longwave net flux. The observed differences may be mainly ascribed to a bad parametrization of the water vapour over the Mediterranean Sea, evidencing the peculiarity of this basin where evaporation phenomena are crucial. For many of the examined formulae, significative improvements of the predictions can be reached by a simple adjustment of the numerical coefficients in the water vapour correction term, although this is not yet sufficient to assure high accuracy. In fact, also the estimates obtained from the revised expressions show a large dispersion around the measured value. This indicate that the radiative fluxes are not univocally determined by the formulae as they are at the present and that they must be revised to take better into account the regional features.

COMPARISON AND UTILIZATION OF NCEP GSM SURFACE STRESS AND ENERGY AND WATER FLUXES FOR COUPLED OCEAN-ATMOSPHERE MODELING AND PREDICTION

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In order to develop a global coupled ocean-atmosphere prediction system, monthly, intraseasonal, interannual and decadal comparisons are being developed between the U.S. National Centers for Environmental Prediction (NCEP) and the Cooperative Ocean Atmosphere Data System (COADS) surface stress, energy, and water fluxes (E-P). Our principal test bed consists of the Oberhuber Pacific basin ocean model and the NCEP reanalysis global spectral atmosphere model (GSM). Preliminary tests with these models, NCEP's reanalysis, and observed fluxes have shown some major differences. In comparison to COADS, the NCEP reanalysis and GSM tropical wind stresses are too weak in tropical regions. Nonetheless, patterns of variability appear realistic and drive realistic interannual to decadal variability in the ocean model. Magnitudes of sensible, latent, and radiative energy fluxes appear comparable in NCEP reanalysis and GSM and COADS , especially in tropical regions. Water fluxes are currently being examined and may eventually prove useful for explaining some local variability. How we are reconciling differences among the atmosphere and ocean models, reanalysis, and observations will be discussed at the meeting.

Investigation of the heat budgets for North Sea and Baltic Sea
Results of model experiments.

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With a 3-d coupled ice-ocean model for the region of the North Sea and Baltic Sea, the development of the heat content in both regions and the atmosphere/ocean heat fluxes are calculated. Results of a eigth years prognostic model run were presented. Interannual variability of the monthly mean fluxes and the oceanic heat content were investigated. Heat fluxes and heat contents of North Sea and Baltic Sea, and their sub basins, will be compared and the influence of different hydrographic conditions and sea ice development in both regions on the heat budget will be discussed. To investigate the influence of flux schemes on the results, some experiments with different flux schemes have been carried out for several years. The sensitivity of the oceanic heat content and the atmosphere/ocean fluxes will be investigated by intercomparisons of the results for different flux schemes.

UNCERTAINTY IN ESTIMATION OF MEAN SOLAR RADIATION FLUXES AT THE BALTIC SURFACE FROM IRREGULAR SHIP-BORNE METEOROLOGICAL OBSERVATIONS

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Meteorological observations made onboard of Voluntary Observing Ships are an important source for climatological information, including incident solar radiation fluxes at the sea surface. These, however, are not measured directly but are estimated by application of radiation parametrisation to meteorological observations. Unlike in the land conditions, at sea, observations are irregular and unevenly distributed in time. The number of observations is often too little to cover all the possible meteorological conditions within a month. These factors make a considerable contribution to the uncertainty in monthly mean flux estimates, especially in case of areas of highly variable meteorological conditions like the Baltic sea region. Long-term regular meteorological observations from chosen island meteorological stations are applied to simulate and analyse the influence of observation number on uncertainty in monthly mean flux estimates. The problem of temporal correlation of meteorological observations is considered.

ON THE SAMPLING ERROR OF MICROWAVE RAIN RATE RETRIEVALS IN THE TROPICAL PACIFIC

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A comprehensive intercomparison of satellite- and doppler radar-derived surface rain rates during four months of the Tropical Ocean Global Atmosphere - Coupled Ocean Atmosphere Response Experiment has been carried out to obtain error bars for instantaneous and averaged products under tropical conditions. Because cruise averaged rainfall from polar orbiting satellites suffer from an undersampling of the diurnal variability of rainfall, special attention has been given to an assessment of the sampling error of satellite-derived cruise averaged rainfall estimates. For each cruise surface rain rates were directly retrieved from two SSM/I instruments flown on the F10 and F11 DMSP spacecrafts and sampled on three different grid spacings (0.5°, 1.0°, and 2.5°). The radar data were sampled onto the same grids in two different ways: 1. As cruise averages from all available radar data, to give the "true" average, and 2. as averages from data during the satellite overpasses. The differences between radar and satellite products have been taken as measures for the sampling error. The analysis shows that the average rainfall derived from one satellite can be wrong by a factor of two. Overestimations are mostly caused by the detection of some events with high rain rates and the assumption that these persist over the whole cruise.

A METHOD FOR DETERMINING THE WIND VELOCITY FROM LIDAR MEASURMENTS OF ATMOSPHERIC AEROSOL.

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The idea of this work is to use lidar observations over atmospheric aerosol for determining the wind velocity. Wind governs both the ocean-atmosphere exchange and the process of generation of atmospheric aerosol. The correlation between the wind velocity and the intensity of aerosol generation is well known. This makes it possible to use the variability of aerosol characteristics for determining the wind velocity. One of the observation methods over aerosol is lidar measurements providing information on the aerosol efficiency for extinction and backscattering. This information can be inverted into the aerosol particle size distribution. According to current theory, the aerosol structure is described by a sum of at least two components relating to smaller and larger particles. The particle size distribution of each component is close to lognormal and is determined by three parameters. The problem of inverting lidar measurements into the distribution parameters amounts to solving an undedertimed system. In the case of two simultaneous lidars, this is a system of two equations for six unknowns. We developed a method for solving problems of this kind. For the numerical experiments, we chose two lidars working at the 0.55 and 10.6 mi, the first wavelength being most sensitive to small particles, and the second one, to large particles. Such a choice makes it possible to retrieve the aerosol particle size distribution for the entire radius interval. The solution to the problem of inverting lidar data into the distribution function is essentially ambiguous. The mean over all solutions satisfying the input data was taken as an answer. The solution was tested for its sensitivity to measurement errors. The retrieval error for the particle size distribution in the 1-5 mi radius interval did not exceed 20% for an aerosol optical characteristic error of 5%. This means the wind velocity error will be approximately three times worse, since it is proportional to the aerosol mass variability, that is, to the third degree of particle radius. Nonetheless, the method has the merit of making it possible to determine the wind velocity over large oceanic areas, and so we believe it to be promising, particularly with airborne lidar measurements, much more accurate that those from space.

THE HYDROLOGICAL CYCLE FROM HIGH RESOLUTION ASSIMILATION EXPERIMENTS FOR SELECTED REGIONS OF THE EARTH

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The reanalyses recently conducted at several institutions are intended to provide internally consistent three-dimensional atmospheric datasets and surface fluxes unaffected by changes in the model or the analysis/forecast scheme.
There are large uncertainties both in analysis or simulation of the components of the hydrological cycle. Therefore the reliability of precipitation estimates created with the analysis scheme is a key question. This is not only valid for long-term averages of precipitation, as necessary e.g. for GPCP, but also for limited areas and high temporal resolutions.
We have conducted experiments in which ECMWF reanalyses are inserted by a Newtonian relaxation procedure into the ECHAM4 GCM, which is run at the same horizontal resolution (T106) as the reanalyses. Precipitation data from the reanalyses and from model simulations for selected regions and periods are compared to observational data sets covering tropical as well as extratropical sites. This includes daily data from West Pacific atoll and low island stations and from the EMEP network.
Results from these simulations and comparisons to observations and analyses will be presented.

OA14 Parametrizations in large scale atmospheric models

Convener: Viterbo, P.

02 Major systematic errors in global coupled models

Convener: Stephenson, D.B.
Co-Convener: Balmaseda, M.A.

MEASURING OF ATMOSPHERE-SEA-LAND INTERACTION IN NORTHERN PART OF CASPIAN SEA

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The behavior of frequency spectra and cospectra of the atmospheric turbulence over the non-homogeneous surface is described through analysis of the data obtained from the shipboard in the expeditions in the northern part of the Caspian sea (Delta of Volga river). These data sets have a wide variety kind of surface: the open water, the channels, the reed fields. The turbulent measurements are accompanied by the simultaneous remote sensing of the sea surface temperature by IR-radiometer. The obtained results indicate that exist the connection between the anomalous behavior of the low-frequency part of the temperature spectra and the mesoscale unhomogenios of sea temperature field. The influence of kind of surface on the turbulent characteristic of the atmosphere are investigated. The wavelet analysis are used for the processing of data.

MODEL DRIFT IN THE SEASONAL PREDICTIONS AT ECMWF

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A coupled model consisting in the ECMWF amospheric model (cycle 15r8), and a version of the Hamburg Ocean Primitive Equations model (HOPE) is currently used in ECMWF to produce seasonal forecasts. The coupled model is integrated forward three times per week for lead times of 6 months. Full coupling is applied between the atmosphere and the ocean. Because of model error, a drift occurs after coupling which is not small compared with the size of the signal being predicted. The main features of the model drift will be discribed, and some possible causes discussed.

ANALYSE OF THE TROPICAL COLD ANOMALY IN THE LMD/IPSL COUPLED MODEL

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The LMD Atmospheric General Circulation Model (AGCM) has been coupled to OPA, the LODYC Oceanic General Circulation Model (OGCM). It does not include a sea ice model but the ocean albedo is supposed to be the ice one when the simulated ocean surface temperature is under freezing. A further version includes a thermodynamical sea ice model fully coupled to the oceanic and atmospheric components. The model has been used for a 30 year-long simulation of the present climate (and in a different but close version, with the sea ice thermodynamics, for a 80 year-long simulation). The simulated climate is approximately stable in global mean and simulates a realistic seasonal cycle. However, it exhibits some regional anomalies which seem to be triggered by various feedbacks. One of the most remarquable is the warm pool erosion and a zonal shape of the surface temperatures in the Pacific and Atlantic Equatorial Oceans. A double ITCZ in simulated in the Pacific and a cold tongue of water goes from East to West at the Equator. This zone is also very dry. The evolution toward this situation is quite fast and once installed it does not evolve with time. In order to point out the causes of these anomalies due to the AGCM part of the coupled model, we compare this coupled model results with the results of a simplified coupled model in which the atmospheric model is the same AGCM. In this model, the ocean component is reduced to the surface ocean and does not simulate the ocean circulation. The ocean model computes the depth of the surface mixed layer and the sea ice cover (thermodynamical model). It uses a prescribed term of ocean heat transport. There exist analogies between the tropical ocean simulated by the two coupled models. Therefore the equatorial anomalies come, at least partially, from AGCM misbehaviour. But the much larger amplitude of the anomalies in the fully dynamical coupled model suggests that the ocean circulation response can trigger the anomaly initiated by the AGCM.

THE COUPLED MODEL INTERCOMPARISON PROJECT

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The Coupled Model Intercomparison Project collects output from global coupled ocean-atmosphere GCMs. We have collected output from 18 models: both "control runs" simulating the pre-industrial climate and future "greenhouse scenarios". Control run seasonal cycles generally differ from observations by an amount that is not much greater than the observational uncertainty. Ocean quantities, however, reveal large inter-model differences. Forced with a common greenhouse scenario, models simulate widely differing amounts of global warming. The database allows further analysis by providing a time series of heat penetration into the oceans.

SENSITIVITY OF THE SIMULATED CLIMATE IN THE TROPICAL PACIFIC TO OCEAN MIXING

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A diagnosis of the systematic errors in the tropical Pacific ocean of a coupled ocean atmosphere general circulation model (GCM) showed that the mixed layer depth was poorly simulated. The inclusion of an explicit mixed layer in the ocean model results in a substantial reduction in the error of the simulated sea surface temperature (SST), precipitation, and wind stress fields. The reduction of error in the (SST) field is zonally asymmetric with cooler SST in the eastern Pacific south of the equator. Warm SST errors in this region have previously been attributed to the poor simulation of marine stratus clouds off the South American coast. The mechanisms behind the SST error reduction are explored. In the GCM which includes an explicit ocean mixed layer it is found that improvements in the simulation of the marine stratus may not be needed.

INITIALIZATION AND CLIMATE DRIFT ISSUES FOUND IN COUPLED CLIMATE MODEL INTEGRATIONS

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In addition to producing a credible simulation of climatic means and variability, an ideal "control" integration of a coupled general circulation model (CGCM) should exhibit negligible climate drift. The presence of climate drift (an unforced trend away from an initial state not associated with internally generated variability about a constant mean state) complicates the analysis of variability and climate change signals in CGCMs. Over time, climate drift can cause a model with a realistic initial state to evolve to a unrealistic climatic state. Modelers participating in CMIP employ various CGCM initialization strategies, yet the development of a CGCM that is truly free of climate drift in all its model components and in all geographic regions has proven elusive. Here, some aspects of the related issues of CGCM initialization, coupling shock, and climate drift are discussed and illustrated with examples drawn from NOAA/GFDL CGCM simulations. In GFDL's CGCMs, the free exchange of fluxes among model components is augmented by the application of heat and freshwater flux adjustments to the ocean. This technique has in some cases controlled climate drift to the extent that simulations in excess of 7000 years have been conducted. In other cases, the use of flux adjustments did not yield successful integrations. The simulated air-sea fluxes and the initialization technique itself are examined in an effort to better understand these variable results.

AN ASSESSMENT OF THE ROLE OF THE ATMOSPHERE IN ANTARCTIC SEA-ICE EXTENSION IN GLOBAL COUPLED MODELS.

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A global sea ice-ocean model (OPAICE) has been coupled with two atmospheric general circulation models (ARPEGE and LMD) in the context of the French climate community activities. Simulations with the same ice-ocean model forced by atmospheric fields are also available for comparison.
In both coupled cases the ice extent in the Antarctic region decreases rapidly, while it remains realistic in forced simulations.
The causes of sea ice disappearance are different for the two coupled experiments : short-comings in heat flux for one model and in fresh water flux for the other one.
Deficiencies in atmospheric parametrizations are identified and their influence on the ocean and on the sea ice characteristics are analysed. Additional sensitivity experiments allow us to clarify the role of atmospheric forcing on the evolution of sea ice extension.

TROPICAL SYSTEMATIC ERRORS OF THE GIOTTO MODEL

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A new global coupled ocean atmosphere model has been developed. The oceanic part consists of the GFDL general circulation model MOM which is worldwide one of the most known and used ocean models. The atmospheric component is formed by the ECHAM-4 model. The physics of this general circulation model were developed at the Max-Planck-Institut in Hamburg and are optimized for climate studies. The coupled model is integrated without flux corrections.
Two coupled runs with different vertical resolution in the ocean model are compared to each other, and major systematic errors in the tropics are investigated. In contrast to observations the mean SST in the coupled model is almost symmetrical around the equator, and the southward extension of the warm surface waters of the warm pool is too small. As a direct result the South Pacific convergence zone (SPCZ) is not present in the model, and in contrast to observations a strong double intertropical convergence zone (ITCZ) is found. These features are common to many coupled models. Another common error of many coupled models is a semi-annual cycle of SST in the eastern equatorial Pacific which is also found in this model. We attribute most of these errors to the vertical mixing in the ocean model. Especially in the eastern tropical Pacific the stratification of the upper 40 meters is too stable. Thus the SST is dominated by heat fluxes which leads to the observed errors.

USING TENDENCY ERRORS AS ADDITIONAL FORCING IN A GENERAL CIRCULATION MODEL

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The long term mean flow simulated in General Circulation Models (GCMs) of the atmosphere exhibits certain systematic errors compared to climatology. These errors are due to errors in the tendencies of the prognostic variables computed from the model equations; ie. forcing errors. Because of energy dispersion and feedback's the spatial distributions of the long term mean forcing errors and the long term mean errors in the prognostic variables themselves are generally quite different. Therefore it is almost impossible to use the long term mean errors in the prognostic variables to deduce where the forcing errors are located in time and space and to deduce their nature. But forcing errors can be obtained as the difference between observed tendencies and model tendencies and they will constitute a space-time map of all the model deficits. In this study the long term mean tendency or forcing errors in both January and July are calculated for all the dynamical prognostic variables in the Arpege/IFS climate model. This is done via assimilating ERA data into the model using a very simple four dimensional data assimilation (nudging). The identified forcing errors are next used as additional forcing in long perpetual Jan. and Jul. simulations. It is seen that the model long term systematic errors are generally reduced by using the additional constant forcing.

Improvements Achieved in a Coupled GCM obtained by Addressing Systematic Errors in the Eastern Equatorial Pacific

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Despite major improvements in the performance of coupled GCMs of the Tropical Pacific, it is still possible to detect the presence of systematic errors. For example, SSTs along the coast of Peru tend to be too warm, and the cold tongue tend to have unrealistic annual variations. Our coupled GCM, which consists of the UCLA AGCM and a version of GFDL's MOM also shared these troublesome features. In addition, the model produced an unrealistically weak interannual variability. This paper describes the improvement achieved by addressing key model parameterizations. The emphasis is on the model performance, rather than on the detail analyses of model features. It is shown that an improved representation of PBL processes in the AGCM results in a drastic improvement of the mean climate and interannual variability. In particular, both the annual mean SST along the equator and the seasonal cycle of the cold tongue are improved. It is shown that at least part of this improvement is due to a better simulation of marine stratus. The feedbacks of the coupled system, however, somewhat reduce the expected improvement. Simulations and experimental predictions of ENSO will be presented at the conference.

A COUPLED OCEAN-ATMOSPHERE CLIMATE MODEL WITH INHOMOGENEOUS GRIDCELL SURFACES

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A new atmosphere-ocean climate model (CM) has been set up to be used in studies of anthropogenic climate change and natural variability. Both the ocean (HOPE) and the atmosphere (ECHAM4) component models have already successfully been used in coupled studies of low-latitude climate dynamics. In these experiments, however, they were not interactively coupled at high latitudes since sea-ice (thermo)dynamics were not accounted for. In order for the CM to be used in long-term integrations we have incorporated a dynamic/thermodynamic sea-ice model.

Fluxes at the ocean-atmosphere interface differ strongly depending on whether the surface is covered by ice or not.The scales involved, however, are much smaller than the grid size of CMs and the dependence of fluxes on the surface properties is highly nonlinear. We therefore allow for a partial ice cover and calculate separate fluxes on the ice-free and ice-covered part of each cell with appropriate parameterisations.

The ocean component model retains the resolution used in the above-mentioned coupled model for low-latitude dynamics (2.8 deg decreasing meridionally to 0.5 deg near the equator). The atmosphere model, however, has a coarser grid (T30 instead of T42). It has been shown that the performance of ECHAM4/T30 in a forced mode is almost as good as that of ECHAM4/T42 with about half the CPU-time requirements only. The sensitivity of HOPE (when forced by ECHAM4 fluxes) to the resolution of the atmosphere can be shown to be low as well.

We present first results of a coupled (control) integration concentrating on the performance at high latitudes.

SENSITIVITY EXPERIMENTS WITH A COUPLED ATMOSPHERE-OCEAN GENERAL CIRCULATION MODEL

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The UCL's coupled atmosphere-ocean general circulation model (AOGCM) is a coarse-resolution model, which does not include any flux correction. Its atmospheric component is an improved version of the atmospheric general circulation model (LMD5) built at the 'Laboratoire de Météorologie Dynamique' of the CNRS (Paris). The oceanic model (CLIO) is a free-surface, primitive-equation model developed at the UCL in Belgium. As many other AOGCMs without flux correction, this coupled model drifts away from realistic climatology. In order to improve the model behavior, a better understanding of its sensitivity to parameterizations is needed. Therefore, we have performed sensitivity experiments in coupled mode on either atmospheric or oceanic parameters. In the atmospheric component, we have altered the vertical resolution, the transition zone between cold and warm clouds, the precipitation rate of cold clouds, and the cloud overlapping along the vertical. For the oceanic component, we investigate the impact of the turbulent closure scheme. The aim of all these sensitivity experiments is to analyze the model drift away from observed climatology and to choice the best parameters.

SENSITIVITY OF SURFACE HEAT FLUX TO PHYSICAL PARAMETERIZATION IN THE IPSL COUPLE MODEL

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The IPSL model is a global ocean-atmosphere coupled model in which we did not make any flux adjustment at the interface. The main climate drifts in this model can be summerized as a cold bias for the Tropics and a warm bias for the high latitudes. These drifts are tightly related to the heat flux reached at the oceanic surface. We study here its sensitivity to the changes of physical parameterizations in the atmosphere. In particular, results on cloud radiative properties, phase transition between water and ice, and convection parameterization will be presented.

OBSERVATIONAL VALIDATION AND IMPLEMENTATION OF MODIFICATIONS OF THE SURFACE ALBEDO PARAMETERIZATION IN THE ECHAM4 GCM

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In order to obtain more confidence in the results from climate simulation, it is essential to address the large uncertainties related to snow cover extent and the albedo of vegetated snow covered land surfaces.

Different global and regional data sources have been used to compare mean monthly albedo, snow cover extent and snow depth with the ECHAM4 GCM. The control experiment consists of a ten-year simulation of the present-day climate at T106 resolution with prescribed sea surface temperature and sea-ice coverage from the atmospheric intercomparison project (AMIP).

This comparison has identified a number of deficiencies inherent in the parameterization of the albedo of (snow covered) land surfaces. To investigate the influence of modifications in the parameterization of ECHAM4, several ten-year model experiments have been performed. These modifications include a changed parameterization of the snow cover fraction, the splitting of the surface albedo into the visible and near-infrared band and the introduction of sub-grid-scale orography. Furthermore. a simple canopy model and an annual cycle of the leaf area have been used to better represent the albedo of forests.

NORTH ATLANTIC OSCILLATION INTERANNUAL VARIABILITY IN OBSERVATIONS AND CMIP COUPLED GCMS RUNS

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The Coupled Model intercomparison Project (CMIP) is aimed at intercomparing and improving the behaviour of global coupled ocean-atmosphere models. Much attention has been focussed on the Pacific basin oscillation, ENSO, which has a large impact on North and South America. The equivalent counterpart for the North Atlantic basin is known as the North Atlantic Oscillation (NAO). Little is known about the dynamics and the variability of the NAO, although it is a dominant mode which explains more than 30% of the total large scale variability of the 500mb geopotential height over the North Atlantic-European area. The North Atlantic Oscillation produces substantial alterations in the intensity and the extension of the North Atlantic wintertime jet storm-track, and has a large impact on the variability of European climate. Realistic simulation of the NAO is crucial in order to reproduce the correct climate variability over the North Atlantic and over Europe. As part of the NAOMIP CMIP sub-project, we have therefore analyzed the NAO variability in 18 CMIP multi-decadal coupled model integrations and have compared the results with those seen in the observed surface temperatures. Simple and multivariate methods have been performed in order to extract the main aspects of the variability and these will be discussed.

TROPICAL PACIFIC VARIABILITY SIMULATED IN A ONE HUNDRED YEAR RUN OF A COUPLED GENERAL CIRCULATION MODEL.

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The LMD global atmospheric model coupled to the LODYC global oceanic model via the OASIS (CERFACS) coupler has been run for one hundred years without flux corrections and with present CO_2 concentrations. Biases of this model are a strong initial cold drift that leads to a warm pool at about 2°C-3°C colder than observations and a predominance for semi-annual rather than annual SST periodicity in the Eastern Pacific. However, this model presents strong interannual departures of the Niño 3 index which reaches amplitudes of 1°C-2°C with a spectrum dominated by a 32-month oscillation. In this paper we examine mechanisms responsible for the simulated interannual behaviour and we compare them with the mechanisms detected in a TOGA-CGCM. We also investigate possible impacts of the systematic biases on the simulated variability.

OA14 Parametrizations in large scale atmospheric models

Convener: Viterbo, P.

03 Sensitivity of radiative pertubations in global coupled models

Convener: Boucher, O.

AN ANALYSIS OF TROPICAL CLOUD RADIATIVE FEEDBACKS IN A COUPLED OCEAN-ATMOSPHERE MODEL.

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Interactions between sea surface temperature, clouds and radiation play a fundamental role in the natural climate variability and in the climate sensitivity to radiative perturbations. We will present an analysis of these interactions in the IPSL global ocean-atmosphere coupled model. First, this analysis will be based on seasonal and interannual variations, and a comparison will be done with satellite observations. Then, we will consider a transient CO_2 experiment of 80 years. A comparison of the tropical clouds feedbacks involved in the CO_2 experiment and in the seasonal or interannual variations will be presented.

SULPHATE AEROSOLS AND TRANSIENT CLIMATE SIMULATIONS

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Based on growing evidence that increases in sulphate aerosols are able to counteract part of the greenhouse gases forcing, an increasing number of GCM studies have started to include the direct effect of sulphate aerosol in their transient climate simulation. This direct effect of sulphate aerosols was represented in these models by an increase in the surface albedo.
Using simpler 2-D (latitude-altitude) climate model we have first compared transient climate simulations forced by -1- the direct effect of sulphate aerosols computed at each model time step by a full radiative code and -2- changes in albedo as done in GCM simulations.
Secondly, we have studied the sensitivity of a transient climate simulation to the chemical composition of sulphate aerosols. We have represented the direct sulphate forcing as sulphuric acid and as ammonium sulphate since lower tropospheric aerosols are largely neutralized by ammonia.

SYSTEMATIC ERRORS IN THE NCAR CLIMATE SYSTEM MODEL: SENSITIVITY TO MODEL FORMULATION

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Several simulations of the NCAR CSM have been performed, ranging in length from 30–300 years. Although the CSM does not use any flux adjustments, these simulations are characterized by a remarkably stable (drift free) climate in the atmosphere, land and upper ocean temperature. Although the surface temperature simulation is quite accurate, significant errors are found in precipitation and other important climate variables. In addition, there is a long term drift in the deep ocean state, which becomes colder and more saline throughout the simulations.
This paper will summarize the major systematic errors in the CSM simulations. The long term drifts, mean biases, and errors in the interannual variability of the model will be presented. The sensitivity of these errors to several changes in model formulation will also be discussed. These changes include: removal of the ocean eddy mixing parameterization; changing the atmosphere-ice drag coefficients; and changing the mean aerosol optical depth.

THE TROPICAL OCEANS AND CLIMATE CHANGE

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Projections of climate change under increasing CO_2 are often made with some assigned role to the ocean by either requiring that it transport no heat (a slab mixed-layer), or by fixing the ocean heat transport. This practice does not account for the dynamic coupling between the ocean and atmosphere. A two-box equilibrium model of the tropical climate is developed to test the sensitivity of the tropical climate to radiative perturbations with different assumptions about the ocean and to analyze the results of GCMs. The model is designed such that the ocean poleward mass flux is dynamically consistent with the mass flux in the atmosphere. This allows for comparison between the case when the ocean heat transport is fixed and when it is interactive. It is found that the ocean can have an impact on the sensitivity of the tropical climate to radiative perturbations mainly through its effect on subtropical marine stratus clouds. We also discuss recent studies that have suggested that an increase in merdional overturning in the low latitude ocean may reduce the sensitivity of the tropical climate to increasing CO_2. It is found that, while this may act to delay the warming due to increased CO_2, in equilibrium, an increase in ocean heat transport actually *increases* the sensitivity of the tropical climate to increased CO_2.

FIRST RESULTS OF A 2XCO2 EXPERIMENT WITH A GLOBAL COUPLED MODEL

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A $2XCO_2$ global coupled simulation is presently performed at CNRM. The models are the Arpège-Climat-V2 AGCM (developped at CNRM) and the OPAice OGCM (developped at LODYC) coupled every day with the OASIS coupler (developped at CERFACS). The AGCM is in truncation T31 with 19 vertical levels; the horizontal resolution of the OGCM is $2° \times 1.5°$ (0.5° at the Equator) with 31 vertical levels; a thermodynamical ice-model is included.
The 2xCO2 experiment is compared to two 100-year long simulations which have been performed at CERFACS: a reference run with a constant CO2 and a run in which the CO2 concentration increase is 1% per year following the IPCC scenario A. In this paper, we will focus on the main results from the 2xCO2 simulation.

THE PINATUBO AEROSOL FORCING - ESTIMATED WITH ECHAM4 AND THE SIMULATED CLIMATE RESPONSE

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A spectral-, space-, and time-dependent set of the Pinatubo stratospheric aerosol was retrieved from different observational sources. The radiative forcing and the climate response were investigated with the Hamburg ECHAM4 GCM. Simulations with and without volcanic aerosol were conducted for different sea surface temperatures. The aerosol radiative forcing is not sensitive to the climate variations caused by SST or the atmospheric response to the aerosols, except in regions with varying dense cloudiness. The sulfate volcanic aerosol produces strong heating in the lower stratosphere (up to 4K in the tropics) and tropospheric cooling in the order of $-5\ W/m^2$. After removing the QBO signal, and accounting for cooling caused by observed ozone depletion, the calculated stratospheric warming corresponds well to the observations. In the troposphere the observed summer cooling is simulated, but is weaker than observed. The winter warming over North America and Eurasia, caused by complicated dynamical effects, is very sensitive to SST. The stratosphere-troposphere dynamical coupling includes intensification of the polar vortex in winter and forcing of the NOA circulation patterns. In our calculations the polar vortex is not as stable as in observations, and temperature anomalies are slightly lower.

PERFORMANCE OF A GLOBAL COUPLED SIMULATION OF CLIMATE CHANGE ASSOCIATED WITH A DOUBLING IN THE CO_2 ATMOSPHERIC CONCENTRATION

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A coupled control simulation with present-day CO_2 atmospheric concentration and a transient CO_2 experiment, in which the CO_2 concentration is increased by one percent per year, are presented. The general circulation coupled model is composed by the ocean-ice model OPAICE, from the Laboratoire d'Océanographie Dymanique et de Climatologie, the atmosphere model ARPEGE-CLIMAT V.2, from Météo-France, and the coupler OASIS 2.1 from the Centre Européen de Recherche et Formation Avancée en Calcul Scientifique. No flux correction are used at the air-sea interface.
The main features of the present climate are reasonably well reproduced in the control simulation. After an initial drift of about 16 years, the dynamics at the air-sea interface stabilizes, although a warm bias is observed in the Sea Surface Temperature near the continental East coasts in the Tropics and in the Southern Ocean. The transient CO_2 simulation starts after the control simulation has stabilized. It shows, at the time of CO_2 doubling i.e. after 70 years, a global warming of about 1.6°C. This value and the main geographical characteristics of climate change are in agreement with previous studies published by other research groups, using either flux corrected or non-flux corrected models.

ST2 Open session on the middle atmosphere (joint with OA)

Convener: Dameris, M.
Co-Convener: Krüger, B.C.

COMPARISON OF CRISTA I DATA WITH ER-2 MEASUREMENTS WITH THE HELP OF A TRAJECTORY MODEL

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CRISTA measurements of CFC11 and HNO_3 over Alaska at an altitude of about 20 km acquired during its first flight in November 1994 were compared with ER-2 observations in the same region over a time interval of eight hours at the beginning of the CRISTA mission. Though miss times and distances occassionally were low, at several locations non-negligible discrepancies occured between the mixing ratios found by both methods. As atmospherical dynamics were high in the investigated region, a two-dimensional isentropic trajectory model using analyzed winds has been applied to shift data from both observations to a fixed point of time for further comparison. The agreement between the mixing ratios from the two observations of both trace gases is shown to improve considerably following this analysis.

SENSITIVITY STUDIES OF THE WINTER MIDDLE ATMOSPHERE WITH AN ADJOINT MECHANISTIC MODEL

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Four dimensional data assimilation has become operational in numerical weather prediction and is now beeing developed for GCM's too. Adjoint model formulations are therefore needed as efficient computational tools. They can also be used for sensitivity studies. We derived an adjoint model version from a global mechanistic model of the middle atmosphere (COMMA) to test physical parameterizations and predictability. To study Northern Hemisphere winter conditions we used three different data sets (SSU, UKMO, ECMWF) covering the time period from October 1991 until March 1997. For the lower stratosphere diabatic heating sources and planetary wave activity will be discussed. Above 10 hPa observations are less frequent and reliable. But accurate knowledge of the radiation and gravity wave fields is strongly recommended e.g. for climatologic calculations. To analyse main contributions to the observed mean stratospheric and mesospheric circulation we used the adjoint system for sensitivity studies taking into account both observations and model dynamics.

THE EVOLUTION OF THE STRATOSPHERE IN A 3-D GLOBAL GRIDPOINT MODEL AT THE PRESENCE OF STEADY STATE ENSO WARM AND ENSO COLD FORCING.

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A global 3-d mechanistic gridpoint model is used to investigate the response of the stratosphere to different climatological lower boundary forcing at 200 hPa. Three 1000 days model simulations with constant lower boundary forcing of the observered geopotential height fields at 200 hPa for January of ENSO cold, ENSO warm, and climatological mean will be compared in detail. Main emphasis is put on pronouncation of the stratospheric winter polar vortex and the intensity and the frequency of occuring stratospheric warmings.
The use of the geopotential heights at 200 hPa of the ENSO cold January leads to a better pronounced stratosheric polar vortex as at the presence of ENSO warm or climatological mean lower boundary forcing.

BISPECTRAL ANALYSIS OF NON-LINEAR TIDAL/PLANETARY-WAVE COUPLING IN THE MESOSPHERE AND LOWER THERMOSPHERE

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Atmospheric tides in the mesosphere and lower thermosphere are known to exhibit considerable short-term fluctuations in amplitude. The mechanisms producing this variability are poorly understood, but are believed to include non-linear interactions between tides and planetary waves. Meteor-radar data collected over the UK between 1989 and 1994 are analysed in the light of current non-linear interaction theory, which suggests the production of secondary waves having frequencies that are the sum and difference of those of the primary waves (the tide and planetary wave) involved in the interaction. Quadratic phase coupling is also predicted between the primary and secondary waves. Bispectral analysis is a powerful technique for investigating the occurrence of such non-linear interactions and the suitability and limitations of this technique as a detector of quadratic phase coupling in geophysical data sets are discussed.

DUAL WAVELENGTH POLARIZATION LIDAR OBSERVATIONS AT TROPICAL LATITUDES DURING THE ALBATROSS CAMPAIGN 1996

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An analysis of high altitude cirrus cloud observations and stratospheric temperatures profiles derived from lidar observations during the ALBATROSS campaign (Atmospheric chemistry and lidar studies above the Atlantic ocean related to ozone and other trace gases in the tropo- and stratosphere) in October-November 1996 are presented. The measurements were performed aboard the German research vessel "POLARSTERN" between 35°N and 45°S. On the basis of dual wavelength polarization data the temperature dependence of the relation between the color ratios of the parallel and perpendicular backscatter coefficients are analyzed. We find an abrupt change at about 240 K which is interpreted as changes of particle shape and/or size distribution. At temperatures between 195 and 255 K a small fraction of the observations are consistent with the presence of small particles with dimensions of less than 0.1 μm. Altitude profiles of stratospheric temperature between 25 and 50 km are calculated by integration of the elastic backscatter signals at 355 and 532 nm. Deviations from the mean profiles are analyzed to study the wave activity in the tropical stratosphere.

MASS EXCHANGE ACROSS THE SUBTROPICAL BARRIER IN A 3-D GLOBAL MODEL DURING A SIMULATED SUDDEN STRATOSPHERIC WARMING.

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The mass exchange from the tropics into midlatitudes across the subtropical barrier during a simulated midwinter stratospheric warming is investigated with a tracer experiment in a 3-d global gridpoint model.
The exchange process is driven by the activity of planetary waves and clearly dependent on height. The largest flux out of the tropics occurs between 15 and 20 km and is directed to the winter hemisphere. A smaller secondary maximum of flux of tropical air to midlatitudes is located near 30 km. Above this level, the flux from the tropics to midlatitudes decreases with height, reaching its minimum near the model stratopause.

STUDY OF WAVE PROCESSES, RAISED IN THE ATMOSPHERE BY THUNDERSTORM, WITH HELP OF MUON HODOSCOPE.

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New method of detection of internal gravity waves in atmosphere by means of ground level cosmic ray observations is developed. Muon hodoscope registers angular distribution of cosmic ray particles, which depends on air density up to 40 km height. The setup, constructed in Moscow (MEPHI), includes the microbarograph with sensitivity about 300 counts/mbar, and the muon hodoscope with area 9 sq.m and the angular resolution about 1-2 degrees. After calibration, this device was put into operation in 1997; it can continuosly register muon flux with statistical accuracy about 0.5% for 1 minute time intervals. The setup operated in the period of thunderstorm activity on May 6-15,1997. The characteristics of wave processes in atmosphere, at this time interval, have been obtained simultaneously with help of the microbarograph and muon hodoscope. It is found, that internal gravity waves, generated in periods of storm activity, are effectively registered by means of muon hodoscope with a level of reliability higher than 99.99 %. It is shown that time of life of a gravity wave in the period preceding the storm exceeds 4 hours, and distance of propagation of such wave can reach 200 km. At this time, the frequency resolution reached with muon hodoscope in peaks of power spectra density was 2-3 %, that is about in three times are better, than at microbarograph. Lengths of a waves in the period, preceding the storm, did not exceed 5 km, and 80 % of periods of gravity waves were in the range from 2 to 6 minutes.

STRATOSPHERIC SUDDEN WARMINGS IN THE BERLIN TSM GCM. PART 2: DIAGNOSIS USING THE TEM FORMULATION

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A ten year integration of the Berlin TSM GCM is used to demonstrate different evolutions of the Arctic polar vortex. The differences between the various wintertime sudden warmings in the Northern Hemisphere are described using the TEM (transformed Eulerian mean) circulation. The streamfunction for this meridional circulation shows a comprehensive picture of the time evolution. The relationship between the intensity of the streamfunction in mid latitudes and polar temperatures is investigated.
Because the streamfunction only describes the zonal-mean structure, the analysis is extended using the EPV (Ertel's potential vorticity), which describes the three-dimensional flow. Selected examples of different events (early wintertime warming, minor warming and major warming) will be discussed in this way.
The combined diagnostic framework incorporating the TEM Circulation and the EPV facilitates a clear description of the early winter conditions of the atmosphere and the evolution leading to the different types of warming events in the model.

FIRST IN SITU TEMPERATURE MEASUREMENTS IN THE SUMMER MESOSPHERE AT ANTARCTIC LATITUDES

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In the austral summer 1997/98 a series of meteorological rockets will be launched from the British Antarctic Station Rothera (68°S,68°W). The falling sphere technique will be used to determine mass density profiles from approximately 95 km to 30 km. Temperature profiles are deduced from these densities assuming hydrostatic equilibrium. Some preliminary results will be shown which represent the first in situ measurements in the upper atmosphere at southern latitudes. In order to study a potential north/south asymmetry of the thermal structure of the high latitude summer mesosphere our results will be compared with falling sphere measurements performed from the Andøya Rocket Range (69°N,16°E) during the summer of 1997.

EVIDENCE OF THE SECONDARY MERIDIONAL CIRCULATION ASSOCIATED WITH THE QUASI-BIENNIAL OSCILLATION OBSERVED IN THE DISTRIBUTIONS OF TRACE SPECIES

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Double peak structures observed in various chemical species in the tropical lower stratosphere imply sinking motion at the equator. The sinking motions are explained in connection with the secondary meridional circulation associated with the equatorial quasi-biennial oscillation. In this study, the meridional divergence points are located objectively in the tropical region at the boundary of rising and sinking motion from HALOE aerosol and HF. The locations of divergence are then compared with zonal wind and calculated meridional divergence. Divergence points are found with maximum easterly wind. In the time-altitude cross-sections of calculated divergence, divergence points are located in the divergence area. Contrary to the divergence points the convergence points are not easily located by the same objective method. The location of those convergence points found are not in agreement with the maximum westerly. The asymmetry between the divergence and convergence points seems to be the background rising motion due to residual circulation in the tropics.

STRATOSPHERIC LOW FREQUENCY VARIABILITY IN MID AND HIGH LATITUDES: "TRIPLE PEAK SPECTRA" OR "BIENNIAL OSCILLATION"?

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In a series of papers, Tung and Yang (1994a,b) and Yang and Tung (1994, 1995) proposed that the QBO related interannual variability of total ozone in mid and high latitudes is characterized by a "triple peak" spectrum with peak amplitudes at periods of 8.5, 20 and 30 months. According to the authors, this spectral signature is the dynamical fingerprint of the tropical Quasi-Biennial Oscillation in mid and high latitudes.
However, Salby (1997) and Baldwin and Dunkerton (1997) demonstrated that the low frequency variability in certain dynamical stratospheric quantities at high latitudes is dominated by variations with periods of 24 months. The origin of this "Biennial Oscillation" is left unexplained.
By performing an EOF analysis on monthly mean fields of the circulation in the northern hemisphere stratosphere, spectral features of the low frequency variability in mid and high latitudes are examined. It is shown that, depending on the time period and pressure level in question, both triple peak spectra and purely biennial modes can be found. Extending the original argument of Tung and Yang by taking the "Ten-to-Twelve-Year Oscillation" (Labitzke, 1987, Labitzke and van Loon, 1988) into account, it is discussed how the observed spectral properties of stratospheric low frequency variability can be understood.

IN-SITU MEASUREMENTS OF NEUTRAL ATMOSPHERE DYNAMICS IN THE POLAR MIDDLE ATMOSPHERE

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On October 12, 1997, a new rocket payload, RONALD, was launched from Andoya Rocket Range (69°17'N, 16°01'E), and a second one will be launched in January 1998. One of the instruments on board, a Rayleigh lidar, observes the total neutral density profile between 50 km and ~80 km on upleg, and from ~80 km to <40 km on downleg. We study the dynamics of the neutral atmosphere, waves and turbulence, with respect to transport mechanisms and energy dissipation rate. We also derive instantaneous temperature profiles from the density profiles. Ground-based lidar observations and falling sphere data allow comparison of this new method of measuring density fluctuations with established techniques. An ion probe and an electron probe on the same rocket potentially allow comparison with the well-known methods using ions as a tracer. The results of these observations will be interpreted in terms of neutral atmosphere dynamics.

VARIANCES AND SPECTRA OF GRAVITY-WAVE VERTICAL VELOCITIES AT MESOPAUSE HEIGHTS

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The EISCAT VHF radar has been used to record vertical winds at mesopause heights on 31 days between June 1990 and January 1993. The data reveal a motion field dominated by quasi-monochromatic gravity waves with periods ~ 30-40 minutes, amplitudes of up to ~ 2.5 ms-1 and large vertical wavelength. In some instances waves appear to be ducted. Vertical profiles of the vertical-velocity variance display a variety of forms and profiles evaluated for consecutive days often show a persistent general shape. The mean variance suggests a semi-annual seasonal cycle with equinoctial minima and solsticial maxima. The mean vertical-wavenumber spectrum evaluated at heights up to 86 km has a slope (spectral index) consistent with observations at lower heights but disagreeing with the predictions of a number of saturation theories advanced to explain gravity-wave spectra. The spectral slopes are steeper (more negative) in summer than in winter and appear to be generally steeper on days with lower mean vertical-velocity variance.

SECULAR VARIATION OF THE 11-YEAR CYCLE OF THE TEMPERATURE, PRESSURE, AND PRECIPITATION IN THE USA FOR PERIOD 1700-1988 ASSOCIATED WITH THE CHANGES OF THE SOLAR ACTIVITY

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Analysis of variation of the temperature, precipitation and pressure in USA from 1700 to the present allows us to assume the existence of a noticeable variation of these parametres in the North American region in the course of the 11-year solar activity cycle. The most interesting results are the spatial and temporal changes of the character of the cyclic variation of the temperature, pressure, and precipitation for all seasons. The physical mechanism responsible for this change seems to be related with the variations of the distribution of the atmospheric pressure and, as consequence, of the circulation in the course of secular cycle of the solar activity.

MODELING OF THE TIME VARIATION OF THE ATMOSPHERIC TEMPERATURE, PRESSURE, AND CIRCULATION ASSOCIATED WITH THE SOLAR PROTON EVENTS

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The time variation of the air temperature, pressure, and circulation in the middle and high latitute troposphere and low stratosphere associated with intense burst of solar cosmic ray flux is modelled. The model is based on supposition that enhances flux of energetic particles causes the apperance in the high latitude stratosphere of an optically active layer. This layer is supposed to reflect about to 10% of the incident short-wave solar radiation. The variation of the radiative balance may produce a changes of the temperature height profile in the high latitude atmosphere, meridional pressure profile, which in turn might cause the change of the zonal circulation. The model data are shown to be in a good agreement with experimental ones.

TROPICAL WAVES IN THE BERLIN TSM GCM: AN INTERCOMPARISON BETWEEN TWO DIFFERENT VERTICAL RESOLUTIONS

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Most middle atmosphere (MA) GCMs are not able to capture the time dependency of the zonal mean flow near the equator adequately. Recent studies imply that higher vertical resolutions of the models lead to a better representation of tropical dynamics, due to the fact that smaller vertical wavelengths can be resolved. To study the impact of the vertical resolution on the tropics, a new version of the Berlin TSM GCM was used: The radiation code was replaced by a state-of-the-art scheme based on the Morcrette parameterisation which was developed by Zhong. The model can be run with two different vertical resolutions. The 34-level version has a vertical spacing of 3.5 km in the MA while the 70-level version reduces the spacing in the MA to approximately 1 km.
The tropical wave spectra simulated by the two versions are compared. The changes in the mean flow evolving at the equator will be analysed. The relationship between the wave spectrum and the mean flow will be discussed.

A METEOROLOGICAL REVIEW OF THE STRATOSPHERIC WINTER 1997/98

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The stratosphere displays a wide range of interannual variability of the evolution of the polar vortex and the associated temperatures in winter and spring. The development of the stratospheric circulation at polar and middle latitudes during the northern hemispheric winter 1997/98 is shown by several relevant parameters such as the temperature, the geostrophic wind, the geopotential vorticity, and the planetary wave activity.
The temperature history of the winter 1997/98 will be compared to the long record of data from the Stratospheric Research Group Berlin to evaluate the possibility of a continuing cooling trend.

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PLANETARY SCALE WAVES OBSERVED IN THE LOWER IONOSPHERE DURING CRISTA I CAMPAIGN

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By means of the MEM spectrum analysis of absorption measurements over Europe and fmin data in Europe and Asia, the main planetary wave type fluctuations (T = 3-25 days) in the upper middle atmosphere CRISTA I campaign (October-November 1994) are studied. Three dominant period bands are found: 3-5, 6-8 and 15-23 (mainly 16-18) days. Similar fluctuations are observed in the prevailing neutral wind near 95 km over central Europe. A very well developed ~10-day fluctuations are found only in fmin and zonal prevailing wind at Irkutsk. For 4-day fluctuations, the westward propagation is found with wavenumber K = 4, while for 7-8 and 16-18 days ones, the eastward propagation with wavenumber K = 3 and K = 1, respectively. This surprising result could not be checked by wind data due to their scarcity. The strength of planetary wave activity at middle latitudes seems to be fairly consistent with the undisturbed (climatological) state of the atmosphere at 80-100 km.

THE SOUTHERN HEMISPHERE WINTER OF 1997

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The meteorology of the 1997 Winter in the Southern Hemisphere is being investigated in some detail using the GEOS-1 data assimilation system developed at NASA GSFC. In this study, particular attention will be devoted to the breakdown of the polar vortex in the early part of November. A range of diagnostics will be used to show the roles of eddy forcing from the troposphere and the radiative effects due to the increasing solar insolation in the polar region. The mixing of air parcels from the polar vortex over the southern hemisphere will be discussed. Short forecasts using the numerical model will be used to examine the predictability of the vortex breakdown, thereby isolating features which are critical to the evolution of the stratospheric flow. Comparisons with other analyses and with total ozone fields will be made.

INITIAL CONDITIONS AND SPIN-UP : COMPARING STRATEGIES FOR USE IN CTMS

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The study of the impact of initial or sustained imbalances in three-dimensional chemical transport models has yet received little attention. For most simulations, assumption is made that the initial perturbed trace constituents fields equilibrate during the first weeks, which are then discarded. In addition, two-dimensional reduced models are often used to generate pre-equilibrated fields at a relatively low computational cost -still, the derivation of three-dimensional fields from these estimates necessarily induces some perturbation. The increase in the realism of CTMs, with the explicit consideration of surface emissions or alternatively of prescribed troposphere-stratosphere exchanges, brings a new incentive to consider strategies to determine the extent of the coupled non-linear effects of dynamics and chemistry, and prospectively to reduce them. We have set up an experiment intending to compare several techniques of initialization starting from two-dimensional fields (zonal average, total column) or from a collection of sonde profiles. We use the REPROBUS CTM of the stratosphere, with three-dimensional equilibrated fields to generate the inputs, in order to isolate the effects of the concurrent initialization procedures. We analyse the various time-scales involved and discuss on the limitations imposed by the present scarcity of the chemical measurements of the middle atmosphere.

ANALYSE OF THE WAVES DURING FRONTS PASSAGES

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Two lee wave experiments were realised in winter 1996-1997 and 1997-1998 in North Scandinavia. Lidars, Radars and ALIS system cameras were located on the two sides of Scandinavia mountains. We analyse here the data from ESRAD MST radar located at ESRANGE [68. °N, 21. °E] in the lee of Scandinavia mountains. This radar operates at 52 MHz, it has 72kW peak power (12 modules of 6 kW each) and a square antenna array consisting of 140-5 element yagis. The yagis can be grouped in different ways and the signal channelled to 6 different receivers. Winds, velocity perturbations associated with waves, and characteristics of turbulence from 1 km up to 10-15km altitude can be studied with a resolution of 300 m. The analysis of the first experiment shows that the waves are often generated during frontal passages which are frequent in this area during winter. We will try this year, by a comparaison of the data during two years to analyse the evolution of the frontal passages and the corresponding winds. Because, the waves are directly correlated to the wind (intensity and direction), we will try to understand better the formation of the waves and their evolution. In addition, we will try to see if we can anticipate the formation of the PSCs with the forecast data from the bulletin weather maps and the ECMWF data.

AN EXAMINATION OF VERY COLD PERIODS IN THE LOWER AND MIDDLE STRATOSPHERE OF THE NORTHERN HEMISPHERIC WINTER

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For different reasons a climatology of very cold periods in the lower stratosphere during winter is needed: An examination of low temperatures in the northern hemisphere is a good indicator for climate change and changes in the atmospheric circulation. Some studies also suggest, that the occurrence of low temperatures is connected to the ozone depletion.
Two main data sets are used for the investigation: daily maps of geopotential height and temperature fields at three stratospheric levels (50, 30 and 10 hPa) which have been analysed at the Freie Universität Berlin since 1963 and several data sets of radiosondes. Using the analyses we carried out the duration and time of occurrence of very cold periods at the levels for every winter season and we found out the locations of the centres of the cold areas during these periods. Moreover we examined the existence of typical circulation patterns when cold periods occurred. The temperature fields are also correlated with the NAO index. Using different reports of radiosonde ascents we investigated the behaviour of extremely low temperatures.

Temporal evolution of stratospheric chlorine monoxide over alpine stations

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The present analysis deals with the chlorine monoxide fields as measured by a ground-based microwave radiometer located at the Plateau de Bure (45°N, France), as measured by the Microwave Limb Sounder (MLS) instrument aboard the Upper Atmosphere Research Satellite (UARS) over the station and as modelled by the three-dimensional SLIMCAT model over the station. Temporal coverage ranges from from fall 1991 up to summer 1997 over a vertical extent from ~50 hPa to ~1 hPa. Since there are very few chlorine activation events in the lower stratosphere over Bure, the analysis will mainly focus on mid-stratospheric ClO behaviour over a short-term period (diurnal variation) and over a mid-term period (seasonal variation) in order to assess any positive trend in the stratospheric chlorine loading over the 5-year period.

EMERGING NEW ATMOSPHERIC CHEMISTRY OF NITROUS OXIDE AND ITS IMPLICATIONS

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Theoretical considerations (Prasad, JGR, **99**, 5295, 1994 & **102**, 21,527, 1997) predict and laboratory experiments (Zipf & Prasad, EOS, Trans. Am. Geophys. Union, Suppl., **78**, S82, 1996 and a paper in preparation) confirm substantial production of N_2O in both the troposphere and the stratosphere from excited nascent O_3 and/or "embryonic" O_3. This production may easily exceed 30% of the "classical" sinks. The observed stratospheric N_2O mixing ratios will not be perturbed by the new source because of: (1) the inevitable loss reactions $N_2O + O_2(b) - N_2 + O_3$ and the $N_2O{\bullet}O_2 + h\nu - N_2 + O_3$ implied by our observed new N_2O formation mechanism, and (2) the observed enhancement in the photolysis of N_2O resulting from the $N_2..O..N_2$ complex formation (to be published).These new sources and sinks of N_2O have many important implications. If we accept the current WMO position of nearly balanced N_2O sources- sinks budget, then the new tropospheric source implies the existence of hitherto unrecognized biogenic sinks. The emerging new N_2O chemistry also implies caution in the use of N_2O as a tracer of dynamical motions. These and other important implications will be discussed.

ON THE EXCITATION OF EQUATORIAL WAVES BY DEEP CONVECTION IN THE NCAR COMMUNITY CLIMATE MODEL

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The vertical propagation of equatorial waves forced in the troposphere plays an important role in the dynamics of the middle atmosphere. In order to study the excitation of equatorial waves in the NCAR Community Climate Model (CCM3), the heating field due to deep convection is analyzed. Projection of the model heating field onto Hough modes gives information about equatorial waves (Rossby, Kelvin and gravity modes) excited over the range of zonal wavenumbers 1-64 and frequencies 0-4 cpd. The Hough spectrum of the geopotential contains all the information necessary to evaluate the upward component of EP flux due to waves excited by deep convection in the CCM3. The results of this analysis are compared to spectra obtained from a similar analysis of the brightness temperature of deep convective clouds (a proxy for convective heating fluctuations in the atmosphere). The comparison indicates that excitation of high frequency waves is underestimated in the CCM3 compared to the observations.

A COMPREHENSIVE THREE-DIMENSIONAL ASSIMILATION SYSTEM FOR OZONE AND OTHER TRACE CONSTITUENTS

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A three-dimensional ozone assimilation system has been developed at the Data Assimilation Office at NASA's Goddard Space Flight Center. The system is driven by analysis winds, and it uses total ozone observations from TOMS and middle/upper stratospheric ozone profiles from SBUV2 for generating global three-dimensional ozone fields at 6-hourly intervals in near-real time. The primary user-group are satellite instrument teams who need reliable background estimates of ozone profiles for their retrieval algorithms. However, access to dynamically consistent ozone fields is expected to be useful also for the investigation of a number of middle atmosphere research topics, such as strato-spheric/tropospheric exchange, atmospheric chemistry. and climate impact of changes in the ozone layer. The system is being expanded to accommodate other minor atmospheric constituents along with ozone. We will give an overview of the system and we will show results from the validation of the three-dimensional structure of the assimilated ozone fields.

RESPONSE OF THE STRATOSPHERE TO INTERANNUAL VARIABILITY IN THE TROPOSPHERE.

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Tropospheric variability such as the Southern Oscillation provides interannual variability in quasi-steady planetary waves near the tropopause. A mechanistic, primitive equation model was integrated under perpetual January conditions with different levels of steady wave forcing at 100hPa to investigate the effect of this variability on the stratosphere. With idealized forcing, differences in the amplitude of the waves at tropopause level lead to qualitatively different states in the stratosphere. These results are viewed in the light of similar experiments with simpler, quasi-geostrophic models. When the idealized forcing is replaced with observed steady planetary waves, similar states are found. These cases will be compared with ensembles of integrations where the perpetual January conditions are replaced by a seasonal cycle and transient wave forcing is included.

RADAR MEASUREMENTS OF FINE STRUCTURES OBSERVED IN THE LOWER ATMOSPHERE

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Measurements using the SOUSY VHF Radar in the Harz mountains in Germany have been carried out in the summer of 1996. For studying the structure and dynamics with high temporal and spatial resolution, the beam was pointing continously in the vertical direction and the range resolution used was 75 m. Fine structures in the echo intensity are observed during a frontal passage and are related to humidity fluctuations. Integrating the high resolution velocity data with time allows us to estimate vertical displacements that can be used to indicate vertical transport. The velocities are analysed harmonically and interpreted as waves with periods of about 6 h and amplitudes of a few cm/s. Observations during a thunderstorm reveal strong convective cells with lifetimes of about 10 to 20 minutes, associated up and down drafts and a series of persistant stable layers in the troposphere ahead of the thunderstorm.

SIMULTANEOUS MEASUREMENTS OF NOCTILUCENT CLOUDS AND POLAR MESOSPHERE SUMMER ECHOES ABOVE NORTHERN SCANDINAVIA IN AUGUST 1997

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Simultaneous and common volume observations of noctilucent clouds (NLC) and polar mesosphere summer echoes (PMSE) were performed in August 1997 above Esrange (67.9N, 21.1E) near Kiruna, Sweden. On two occasions. NLC layers were observed by lidar with mean backscatter ratios of 12 and 25 at 532 nm and mean altitudes of 84.3 and 83.4 km, respectively. During both NLC events, several PMSE layers were observed by the MST radar on Esrange with S/N up to 5 dB in an altitude range between 82.0 and 88.9 km. The first of these NLC events has also been recorded by a camera placed about 380 km south of Esrange. During the jointly observed NLC/PMSE events NLC signals occurred with and without PMSE present in the same scattering volumes at same times, as well as higher altitude PMSE layers ondulating correlated with the lower altitude NLC-layer. One of the PMSE layers appears to convert to a NLC layer during the observations.

THE PECULIARITIES OF THE LOWEST OSCILLATION'S MODE IN THE ATMOSPHERE WITH REALISTIC TEMPERATURE DISTRIBUTION

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A model analysis of the properties of the lowest oscillation's mode is considered. Any vertical profile of the atmospheric temperature can be well approximated as a ratio of two polynomials of the same power. For considered altitude temperature profile, an exact solution determined the properties of the lowest mode of oscillations in the non-isothermal atmosphere is found. The frequency of the lowest mode is also determined. The influences of the nonlinear waves absorption at this frequency is investigated so far as the oscillation's amplitude has the fast altitude growth. Different upper boundary conditions are considered.

MIDDLE ATMOSPHERE WINDS AT OBSERVATOIRE DE HAUTE-PROVENCE (44°N) BY DOPPLER RAYLEIGH LIDAR: SEASONAL AND PLANETARY SCALE VARIABILITY.

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The regular operation of a Doppler wind lidar since August 1995 at Observatoire de Haute Provence (44°N) has offered the first data base of continuous remote measurements of horizontal winds in the middle atmosphere. Such set of data consists in vertical profiles of zonal and meridional components with sufficient vertical resolution and accuracy to study mean winds and planetary scale disturbances in the whole stratosphere and lower mesosphere from 15 to 50 kilometers altitude. The very first climatology of the mean wind has been obtained and compared with climatological empirical models such as the MSISE wind model and with the analysis of the European Center for Medium range Weather Forecast (ECMWF) (for the common vertical range 15-30km). This climatology relies on 3 years of measurements and the seasonal variation and the total day-to-day variability are reported. For a specific operation with dense measurements coupled with temperature measurements from a co-located Rayleigh Lidar, a detailed analysis of the planetary waves activity over OHP will be performed with specific focus on the frequency content for and phase mismatch between the different parameters.

GCM SIMULATION OF STRATOSPHERIC BACKGROUND AEROSOL

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Stratospheric aerosol has various effects on the global climate system. It disturbs the radiative balance and changes the chemical composition of the atmosphere due to heterogeneous reactions. Therefore, as one part of a chemical-microphysical model, a stratospheric aerosol model is implemented in the Hamburg climate model ECHAM4. This model treats the formation, the development and the transport of stratospheric sulfuric aerosol. The size distribution and the weight percentage of the aerosol is calculated dependent on the H_2SO_4/H_2O-concentration, temperature and pressure. Homogeneous nucleation, condensation (evaporation), coagulation, water-vapor growth, sedimentation and stratospheric sulfur chemistry are included. Additionally, the microphysical model is coupled to a tropospheric sulfur cycle. This sulfur cycle treats the natural and anthropogenic emissions, chemistry, dry and wet deposition and chemistry of DMS, SO_2 and SO_4^{2-}. Due to this combination of microphysical model and sulfur cycle, globally and seasonally different SO_2- and SO_4^{2-}-sources for stratospheric aerosol are taken into account. First results of the 3d-simulation show that the model is able to reproduce the observed surface concentration. The formation of new particles through homogeneous nucleation takes place in the lower stratosphere and in polar spring. Here results of a multiyear run are presented and compared to observations.

MEASUREMENTS OF GRAVITY WAVE ACTIVITY AND THERMAL STRUCTURE IN THE ARCTIC STRATOSPHERIC VORTEX

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The stratospheric observatory in the Canadian High Arctic at Eureka (80°N,86°W) is ideally situated to observe processes which are associated with the dynamics of the polar vortex. Lidar measurements at Eureka have shown a clear pattern in the distribution of gravity wave activity and thermal structure within and around the vortex. Gravity wave activity is a maximum in the jet of the vortex and a minimum within the vortex core. The warmest region of the upper stratosphere is within the core while the coldest region is outside the vortex. These observations also indicate that there is an annual midwinter warming of the upper stratosphere within the core. Coincident with this warming is an observed increase in gravity wave activity in the jet. The distribution of gravity wave activity can be explained by the Doppler shifting and critical level filtering that is imposed by the background wind profile. We propose that increased gravity wave dissipation above the jet forces the flow toward the vortex core where it descends and warms by adiabatic compression.

TRACE GAS MEASUREMENTS IN THE ARCTIC WINTER STRATOSPHERE WITH THE AIRBORNE SUBMILLIMETER SIS RADIOMETER

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The Airborne-Submillimeter-SIS-Radiometer (ASUR) measures thermal emission lines of stratospheric trace gases at submillimeter wavelengths. It is operated aboard the German research aircraft FALCON at flight altitudes of 10-12 km to avoid the absorption caused by tropospheric water vapor. Volume mixing ratio profiles can be retrieved from the pressure broadened spectral lines using non-linear least squares inversion algorithms. Measurement campaigns with respect to ozone depletion in the Arctic winter stratosphere have been carried out in yearly intervals since 1992 to investigate the distributions of the radical Chlorine monoxide (ClO), the reservoir species Hydrochloric acid (HCl), the chemically inert tracer Nitrous oxide (N_2O), and Ozone (O_3). A large dataset has been obtained which has been used to validate the 3D chemical transport model SLIMCAT inside, at the edge, and outside the polar vortex.

LEE-WAVES IN THE STRATOSPHERE

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The occurrence of polar stratospheric clouds (PSC) under unfavorable environmental conditions has raised the question, whether large amplitude gravity waves can lead to parcel cooling rates suitable for PSC formation. We have investigated the problem under which circumstances lee waves can penetrate through the Tropopause and cause significant wave motion in the lower Stratosphere.
The investigations have been performed by linear and nonlinear numerical models for idealized and observed mean vertical profiles of wind and temperature upstream of mountain ridges. Some results obtained for the Norwegian mountains will be compared to observed lee-waves and related PSC formation.

CLIMATOLOGY OF ARCTIC AND ANTARCTIC POLAR VORTICES USING ELLIPTICAL DIAGNOSTICS

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The climatological structure, and interannual variability, of the Arctic and Antarctic stratospheric polar vortices are examined by analysis of elliptical diagnostics applied to 18 years of potential vorticity data. The elliptical diagnostics define the area, center, elongation and orientation of each vortex, and are used to quantify their structure and evolution. The diagnostics offer a novel view of the well-known differences in the climatological structure of the polar vortices. There are substantial differences in the distortion of the vortices from zonal symmetry; the Arctic vortex is displaced further off the pole and is more elongated than the Antarctic vortex. While there is a mid-winter minimum in the distortion of the Antarctic vortex, the distortion of the Arctic vortex increases during its life cycle. There are also large differences in the interannual variability of the vortices: the variability of the Antarctic vortex is small except during the spring vortex breakdown, whereas Arctic vortex is highly variable throughout its life-cycle, particularly in late-winter. The diagnostics also reveal features not apparent in previous studies. For example, there are periods when there are large zonal shifts in the climatological locations of the vortices, and in early winter there are two preferred longitudes of the center of the lower stratospheric Arctic vortex.

ATMOSPHERIC TRACE GAS CORRELATIONS AS MEASURED BY CRISTA

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The CRISTA Instrument (CRyogenic Infrared Spectrometers and Telescopes for the Atmosphere) was flown on the Space-Shuttle missions STS 66 in November 1994 and STS 85 in August 1997. Global measurements of trace gases in the spectral range from 4 to 71 μm with high spatial resolution during free flying periods of 8 days in both flights were performed, and about 50000 height profiles were obtained in each flight. Correlations between the mixing ratios of several stratospheric constituents (e.g. N_2O, CH_4, HNO_3, O_3) for the first flight will be discussed and compared with model calculations.

MIDLATITUDINAL LOWER IONOSPHERE DISTURBANCES CAUSED BY NATURAL SOURSES

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There are presented experimental data on natural disturbances (powerful earthquakes, the solar terminator, strong thunderstorms, solar flares and magnetic storms) having effects on midlatitudinal ionospheric D-region parameters, characteristics of partially reflected (PR) signals and radio noise on f =2-4 MHz. There are investigated parameters of wave disturbances (type, periods, durations, and velocities) arising over these periods in the D region. Our investigations were carried out by the PR technique within a 1977-1997 period under different solar and geophysical conditions; the observation durations being minutes-days; ~30 to 200 samples covering each source of the disturbances. The authors have been supported by STCU Grant 471.

IONOSPHERIC PARAMETER VARIATIONS IN THE LOWER D REGION DURING MAGNETIC STORM

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Using the partial reflection technique, it is found that the electron collision frequency increases more than 50% in the lower part of the D region ($z < 70$ km) due to precipitating energetic particles during magnetic storms (MS). Measurements made during 3 MS in a 1984-1985 period near Kharkiv show that the precipitation occurs in a cource of ~10 days after the MS. On these events, intensive partial reflections are observed from heights of $55 < z < 70$ km, and the electron number density increases several times. Calculations of flux intensities of precipitating energetic particles and ion-production rates are presented. The authors have been supported by STCU Grant 471.

ON THE VERTICAL WAVE-ENERGY PROPAGATION FROM TROPOSPHERE TO STRATOSPHERE IN DIFFERENT GEOGRAPHICAL REGIONS

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The vertical energy propagation connected with planetary waves controls up to a high extend the stratospheric circulation. The paper is concerned with the question of longitudinal and regional dependence of vertical wave-energy propagation.
For the 16 winter seasons of ECMWF reanalyses data covering 17 pressure levels the extended Eliassen-Palm-flux (EEPF) has been calculated for different characteristic timescales. The analyses show that the most dominant vertical synoptic wave-energy exchange with stratosphreric heights takes place over the North Atlantic region (NAR). In contrast to other geographical regions only in the NAR the synoptic wave-energy is able to penetrate up to stratospheric heights. Additional to the EEPF analyses this wave-energy window can be found in Principal Oscillation Patterns (POP) analyses, too. The so detected coherent wavepackets with oscillation periods between 5 and 10 days propagate only over the NAR up to the stratosphere. Besides this regional synoptic features it has been detected a more global travelling mode in the stratosphere with oscillation period of about 2 weeks. Both significant different POP structures may be interpreted in the framework of a linear theory.

GLOBAL MODEL OF CIRCULATION OF THE MIDDLE AND UPPER ATMOSPHERE

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The numerical three-dimensional model of the atmosphere circulation at altitudes from 20 to 300 km is suggested. This model is developed on a basis of the empiric models of the structural parameters of the strato-thermosphere. As the analysis shows, it is just such models which in the present time reproduce more precisely the observed systems of circulation. However, at the middle atmosphere heights, in distinction to the thermosphere, we have only the zonal-averaged distribution of the temperature, pressure and density. Thus, we have to calculate the atmosphere parameters variations conditioned by the tide oscillations and quasisteady planetary waves. We achieve this including the solution of the heat balance equation into the numerical model. The necessary non-adiabatic sources of the heating are found from the energy equation. in doing so, the circulation was beforehand calculation from the empiric models of the atmosphere which were supplemented at the stratosphere heights by the sources of the tide oscillations excitement. The variations of the atmospheric parameters connected with the planetary waves propagating from the troposphere were taken into account by setting the geopotential disturbances at the lower boundary.

GLOBAL STRATOSPHERIC CIRCULATION ANALYSIS BY MEANS OF SPECTRAL DECOMPOSITION

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To give an objective characteristics of circulation patterns the spectral structure of stratospheric fields (temperature and geopotential) is analyzed in terms of the spherical harmonics with the aim to compare the long-term behaviour and connections to some extra-terrestric influence and circulations patterns. The daily meteo data from Free University Berlin cover more or less the period 1976–96 and are available for stratospheric levels 50, 30 and 10 hPa. The analysis of annual course of spherical harmonics is introduced as well as the comparison of the principal wave components changes with respect to the changes of different sets of solar, geomagnetic and global circulation indices. The interannual variability with special emphasis to the QBO and ENSO is also studied. Quite high correlation is found for some wave numbers.

WATER IN THE ATMOSPHERE AND MESOSPHERE

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Water is the only substance that occurs in all three phases, gaseous, fluid and solid – monomer and polymer (cluster) – in the Earth's atmosphere. The spatial and temporal distribution of H_2O is not only very important for the climate, weather, biosphere and atmospheric chemistry – homogeneous and heterogeneous – but also for the propagation of electromagnetic waves through the atmosphere. The climate of the Earth has never been static. It is very much different now from what it was during cretaceous when dinosaurs dominated the life of Earth. Since climate is the sum of all weather over longer periods of time we must ask ourselves how much climate, like weather, is predictabel. Water vapor in the atmosphere can be measured using microwave techniques, such as those used in experiments made by the MPAE. The major questions are now:

1. How much extraterrestrial water exists in the atmosphere?
2. How variable is the total hydrogen budget over a longer time period?
3. Is the polar mesosphere an early warning system for global change?
4. Can the strength of El Nino better estimated using microwave measurements in the equatorial tropopause?

MEAN DIURNAL VARIATIONS OF PMSE AND WINDS AS MEASURED WITH THE ALOMAR-SOUSY RADAR DURING THE SUMMER MONTHS FROM 1994 TO 1997

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VHF radar observations of the structure and dynamics of Polar Mesospheric Summer Echoes (PMSE) have been carried out at Andenes (69.3° N, 16.0° E) using the ALOMAR SOUSY radar operated at 53.5 MHz for four summer seasons from 1994 to 1997. The radar measures 3D winds and reflectivity profiles mainly with a range resolution of 300 m and a time resolution of about 30 sec. The total number of about 3500 hours observation time allows detailed studies of the seasonal variations of PMSE which are closely connected to the cold temperatures at the mesopause region at high latitudes during the summer months.
Based on these data hourly means of the reflectivity and winds have been determined in order to describe the diurnal variation of the occurrence of the PMSE which is characterized by a minimum around 19 - 21 LT and a maximum at about 14 LT. This behaviour is discussed for the whole data set and for partial periods of the PMSE season in relation to the mean winds and tides derived from the ALOMAR SOUSY radar using the Doppler beam swinging technique.

MEASUREMENTS OF SUMMER MESOPAUSE REGION ZONAL WINDS OVER CENTRAL AND EASTERN EUROPE

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Measurements of the zonal prevailing wind in the mesopause region, i.e. between 80 and 100 km height have been carried out during three campaigns in August 1994, 1995 and 1996 by the Kharkov State Technical University of Radioelectronics, Ukraine, with the aid of a meteor radar at 50°N, 37°E. The results are compared with the total reflection low-frequency mesopause radio wind measurements at 52°N, 15°E that are carried at the Collm Observatory of the University of Leipzig, Germany. While in 1994 and 1995 the zonal prevailing winds at Kharkov and Collm are similar, in 1996 at Collm lower prevailing winds are measured. The amplitude of the semidiurnal tide at Kharkov is larger than at Collm, while generally the phase is in good agreement at both sites. The amplitude of the quasi 2-day wave is low during each of the periods. Only in 1995 a moderate event has been identified. From phase comparison a zonal wavenumber of 2.6 is inferred.

CLIMATOLOGY AND TIDAL INTERACTIONS OF SHORT-PERIOD GRAVITY WAVES AT METEOR HEIGHTS

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A twin-beam meteor radar located in the UK has been used to measure horizontal velocities at meteor heights between 1989 and 1994. Although the radar cannot easily identify individual gravity waves within the broad meteor collecting volumes, the variance of the velocities nevertheless provides a statistical measure of the activity of the gravity-wave field. Using this measure of wave activity, a seasonal cycle for gravity waves with periods < 1 hour is revealed which shows solsticial maxima and equinoctial minima. There is considerable year to year variability. A time-series analysis of the data indicates that the wave activity is strongly modulated by interaction with both the 12 and 24 hour tides. The seasonal behaviour of this modulation is investigated and defined.

LABORATORY AND MODELING STUDIES OF CO_2 + O(^{1}D) ISOTOPIC EXCHANGE

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Carbon dioxide in the middle atmosphere is mass independently enriched in oxygen isotopes ($\delta^{17}O \neq 0.5\delta^{18}O$) relative to tropospheric values, with the enrichments typically increasing with altitude. That is, with increasing altitude, the $^{17}O/^{16}O$ ratio shows an additional enhancement over what is normally expected on the basis of the $^{18}O/^{16}O$ increase. As tropospheric CO_2 has a mass dependent isotopic composition that is relatively constant, isotopic measurements of atmospheric CO_2, combined with a quantitative understanding of the enrichment mechanism, will yield valuable information regarding important atmospheric processes. It is known that the mass independent enrichment in stratospheric CO_2 occurs when CO_2 quenches an O(^{1}D) formed during the photolysis of O_3, but the details of this process remain uncertain. We have performed a series of laboratory and numerical experiments designed to study the time evolution and final equilibrium values of the CO_2+O(^{1}D) reaction. Developing a quantitative understanding of the middle atmospheric CO_2 enrichment process is important because the mass independent signature can provide information regarding atmospheric dynamics, the isotopic composition of atmospheric O_3, and O(^{1}D) concentrations in the middle atmosphere.

THE QUASI 16-DAY WAVE IN THE SUMMER MIDLATITUDE MESOPAUSE REGION AND ITS DEPENDENCE ON THE EQUATORIAL QUASI-BIENNIAL OSCILLATION

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From 16 years of daily estimates of the summer midlatitude mesopause region zonal prevailing wind measured at the Collm Observatory of the University of Leipzig, Germany, long-term variations in the period range of planetary waves (10-20 days) are detected. Although the direct propagation of these waves from the troposphere into the mesosphere is not possible because of the wave filtering through to the summer stratospheric and mesospheric easterlies, in some years oscillations are found that can be connected with planetary waves, supporting the theory of the propagation of these waves from the equatorial region to the midlatitude and polar upper mesosphere along the zero wind line. This wave activity is dependent on the equatorial quasi-biennial oscillation (QBO), so that in general during the east phase of the QBO the planetary wave activity is small, while during the QBO west phase it can be larger. The influence of the QBO on the planetary wave activity is modulated by the 11-year solar cycle, so that the strongest QBO signal is found during solar maximum.

TRANSPORT ACROSS THE SUBTROPICAL BARRIER AS OBSERVED BY THE CRISTA EXPERIMENT AND THE KASIMA/CTM

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On November 3, 1994 the Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere (CRISTA) was launched aboard the Space Shuttle Atlantis into a 300 km, 57° inclination orbit and measured about 50,000 height profiles of limb radiance spectra. On November 6 1994 CRISTA analyses of N_2O and HNO_3 show three narrow tounges of mixing ratios pointing from the tropics poleward and eastward. Idealized transport experiments with the KArlsruhe SImulation model of the Middle Atmosphere (KASIMA) strongly support the hypotheses that these tounges are due to an advective transport process on a timescale of several days. The analyses is based on a subjective comparison as well as on objective statistical correllations between the CRISTA and the KASIMA analyses.

TRANSIENT PLANETARY WAVES STRUCTURE IN THE MIDDLE ATMOSPHERE DURING 1991-1992 : UARS DATA ANALYSIS AND NUMERICAL MODEL RUNS

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Temperature UARS data (ISAMS instrument) from 100 mb up to mesospheric levels jointly with UKMO assimilated data and lidar temperature data were used to study character periods and wave numbers of transient planeta ry waves in the middle atmosphere with special attention to waves intensity at higher levels. Due to rather poor temperature mesurements by ISAMS instrument (in spite of its possibility for measurements in mesosphere) MEM spec tral teknique was used. The results of data analysis has revealed different character periods of oscillations like 2-3, 5-7 and 9-15 days which exist also in the mesosphere Similar periods were found also in D-region radio wave absorbtion. It is interesting to pay attention to the wave with the period near 2-3 days which has zonal wave number m=3. Spectral density of temperature for m=1,2,3 from 100 to 0.01 mb was calculated. The transient planetary waves existance at high levels of the middle atmosphere permits to suppouse of its penetration from troposphere. Numerical model runs support this idea. The waves which were obtained as a result of data analysis are in a good correspondence with "resonant" or normal waves which were genarated in model.

SIMULATIONS OF MIDDLE ATMOSPHERE WINDS AND COMPARISON WITH LONG-TERM MESOPAUSE WIND MEASUREMENTS AT COLLM OBSERVATORY (52° N 15° E)

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Simulations of wind field dynamics in the upper mesosphere and lower thermosphere (MLT) region are performed with the COlogne Model of the Middle Atmosphere (COMMA) at the Leipzig Institute for Meteorologie (LIM). Numerical simulations in a nonlinear model are able to give an insight into energy transfer and coupling processes in the MLT region. Well analyzed wind measurements with high reliability of the dynamical parameters are necessary for an accurate interpretation of model results and to bring effects of tides and planetary waves into focus, that are of actual interest. In this connection the results from the Comma model of the middle atmosphere are compared with the long-term midlatitude wind measurements from the Collm observatory.

THE "16-DAY" EASTWARD-TRAVELLING WAVENUMBER 2 IN THE STRATOSPHERE: A COMPARISON BETWEEN THE HEMISPHERES

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A wave calender of the Northern Hemisphere (NH) stratosphere has revealed an interesting feature: a "quasi-16-day" eastward travelling planetary wavenumber 2, which occurs during Winter at high latitudes. This wave is a well-known. regularly occurring phenomenon in the Southern Hemisphere (SH). where its interaction with the quasi-stationary forced wavenumber 1 is related to a quasi-periodic amplifications of that wave; this can lead to minor midwinter warmings, as occurred in August-September 1988. This warming mechanism is quite different from that of major warming events in the NH.
In this study, clear evidence of an eastward travelling wavenumber 2 event in the 1982/83 NH Winter is presented. It is related to several minor warmings. This case study will show that the 1982/83 NH and 1988 SH minor warmings have develop similarly. Nevertheless, the wavenumber 1/wavenumber 2 interactions in the two cases are different.

STRATOSPHERIC SUDDEN WARMINGS IN THE BERLIN TSM GCM, PART I: SENSITIVITY TO RADIATIVE HEATING RATES AND RESOLUTION

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Erlebach et al. (1996) reported on the successful simulation of sudden stratospheric warmings in a 28-year integration of the Berlin troposphere-stratosphere-mesosphere general circulation model (GCM). The model was able to capture many of the observed characteristics of the warmings, e.g. major and minor events, their frequency and coupling to the troposphere. Some details of the evolution of the warmings however could not be reproduced properly by the model: e.g. the erosion of the polar vortex during major warming events and the restoration of the wintertime circulation. It was argued that the low horizontal resolution or a too weak radiative forcing might be responsible for that. Here, the discussion of these questions is continued using the results from a 10-year integration of a new model version. Major differences include an improvement of the IR-radiation parametrization in the stratosphere and of the ozone climatology. Different types of sudden stratospheric warmings developed during the 10 northern hemisphere model winters, enabling a systematic analysis of the new model results with respect to deficiencies identified in the previous model version. The influence of the radiation and the model resolution on the simulated climatology and interannual variability will be discussed in some detail.

ST16 Stratosphere-troposphere-exchange (co-sponsored by OA)

Convener: Wirth, V.
Co-Convener: Haynes, P.H.

FINE STRUCTURE OF WATER VAPOUR TRANSPORT AT THE POLAR VORTEX

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The fine structure of water vapour transport at the edge of the polar vortex in northern winter has been investigated with a 3-dimensional model. The experiments were performed with a primitive equation mechanistic model. It was forced using observed 200hPa geopotential height fields for typical dynamical situations in wintertime. It has been run with coupled chemistry, using an accurate semi-Lagrangian transport scheme at a horizontal resolution of 1.4° x 1.4° and a vertical resolution of 1.4km. The fine structure of the water vapour fields near the polar vortex edge are examined. The contributions of chemical and dynamical processes are investigated.

ST16

CORRECTION FOR PHASE ERRORS IN LAGRANGIAN MODELLING OF TRACER FILAMENTS

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The main mechanism of mixing of chemical species in the stratosphere is thought to be a combination of horizontal advection and vertical shear. The result of this mixing is, generally, a filamented structure of the tracer fields, both horizontally and vertically. This structure has been confirmed, for example, by various *in situ* aircraft measurements and balloon soundings. Recently, efficient Lagrangian based modelling tools have been developed to asses the fine-scale structure in the tracer fields. However, these tools are thought to be of limited importance for the prediction of measurements because they often show poor correlation between reconstructed and measured tracer concentration.
We show that the main sources of this poor correlation are phase errors in the advected structures and errors in the determination of the reconstructed tracer field at the exact time of measurement. This is proven by correcting for these errors through a process of optimization (under certain constraints) of the correlation between measured and reconstructed tracer concentration and by explicitly taking into account the exact time of measurement. After these corrections the linear correlation between the measurement and the reconstruction may be higher than 90%.

ISENTROPIC AND THREE-DIMENSIONAL TRAJECTORIES NEAR THE TROPOPAUSE

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The effect of including three dimensional motion near the tropopause onstratosphere troposphere exchange is investigated using isentropic and three dimensional trajectories. Recent work has suggested that the differences between two and three dimensional motion may be important on a seasonal timescale (Eluskiewicz, Geophysical Research Letters 23,1996). Here we show that where diabatic processes take parcels through the region of large vertical shear near the mid-latitude jet, the effect on the shape of small scale structures, such as tropopause folds, is significant even on timescales of a few days. This suggests that a proper treatment of stratosphere troposphere exchange mechanisms near to the tropopause requires a full three-dimensional treatment.

LAGRANGIAN CLIMATOLOGY OF A SIMPLIFIED GENERAL CIRCULATION MODEL

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We investigate the Lagrangian climatology of a Simplified General Circulation Model. The model integratés directly the primitive equations for the atmospheric fluid on a sphere. It make the assumption of dry air and consider no orography. Simple linear parametrizations are used to describe dissipative and radiative processes.
Lagrangian tracers have been seeded on isentropic surfaces in the Eulerian field and their trajectories have been integrated in time, both using an isentropic 2D approximation and using full 3D advection.
We discuss the presence of barriers to transport and the possibilities of interemispheric and troposphere-stratosphere exchanges. Measure of the absolute meridional dispersion, spectra and histograms of tracers velocity allow to investigate the different dynamic Lagrangian behaviours for the regions separated by barriers.
To explore the role of seasonal forcing, we compare simulations with annual cycle with perennial spring runs. From the comparison of Lagrangian velocities histograms arises that the application of seasonal forcing does not change significantly the mean dynamics simulated by the model. This result is confirmed by the evaluation of Lagrangian velocities power spectra.

Heterogeneous chemistry in the tropopause region

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This presentation elaborates on the possibility of chlorine activating heterogeneous chemistry in the tropopause region occurring on cirrus cloud crystals, supercooled droplets, layers of increased numbers of small aerosol particles, and solution droplets of the upper tropospheric background aerosol. The high water vapor content, low temperatures, and slow photochemical recovery times near the tropopause make this region susceptible to heterogeneous processing, just as the extreme cold temperatures over the poles do for dryer air at higher altitudes. A detailed 2-D model study by Solomon et al., 1997, revealed that heterogeneous chemistry on the aerosol of the tropopause region could make a significant contribution to the ozone depletion in northern mid-latitudes. Input for these model calculations are climatological SAGE II satellite observations of cirrus cloud optical depths and cloud occurrence frequencies from 1988 and 1989, i.e., years of relative volcanic quiescence. Because of variations in observed cloud occurrence frequency and in photochemical and dynamical timescales, the presence of cirrus clouds likely has its largest effect on ozone near the northern hemispheric midlatitude tropopause. There the low background ClO mixing ratios could be enhanced by heterogeneous reactions by factors of 30, according to the model results. Since the reformation of HCl is a very slow process in the lowermost stratosphere, the relaxation of ClO to the clear sky background abundances can take hours to days depending on latitude and season. Thus, elevated ClO might persist longer than the cloud event itself. Due to the lack of chlorine nitrate, HCl, and ClO observations the discussed processes have to be considered as hypothetical. However, consideration of upper tropospheric heterogeneous chemistry might contribute to explain the shape of the vertical ozone depletion profile.

LITHOSPHERIC STRUCTURE BENEATH THE SOUTHERN FRENCH ALPS INFERRED BY BROAD-BAND ANALYSIS.

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We present the preliminary results of a field experiment made as part of the GéoFrance 3D Alpes programme. During this passive seismological experiment, broad-band stations (CMG40 and CMG3) were set up during periods of 3-4 months at different sites to complete the recently installed TGRS and ROSALP broad-band networks in the french Alps. We analyse teleseismic P-waves and their coda in order to constrain the lithospheric structure beneath the western Alps. We take advantage of the three components to compute Receiver Function isolating by the way the local Earth structure response beneath each station. The functions are inverted (in shape and amplitude) to recover the vertical variation of the waves velocities up to 50 km. Furthermore, we are looking for a model below 50 km by stacking data from different events to increase the signal-to-noise ratio of the 450- and 650 km discontinuities. The short distance between the station gives us a good control on the lateral variations of the lithospheric structure which we try to relate to the geodynamical context of the region.

A CLIMATOLOGY OF STRATOSPHERE - TROPOSPHERE OZONE EXCHANGE FOR THE ATLANTIC - EUROPEAN SECTOR

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Quantification of stratosphere-troposphere transport is fundamental to the study and modelling of tropospheric and stratospheric chemistry. Here the annual distribution of upward and downward ozone flux across the tropopause is estimated in the 40°-60° latitude band covering the Atlantic and Europe sectors for the period May 95-May 96. The study is based upon aircraft measurements (NOXAR project) and a pseudo-Lagrangian trajectory calculation model using ECMWF analysed data. The focus is on strong exchange events involving trajectories directly crossing the 2PVU-tropopause, and ozone mass conservation along trajectories is assumed. This method delivers estimates of the means of the: exchange probabilities; ozone concentration of the exchanged masses; origin and destination pressure levels of the exchanged parcels. The mean O_3 vol. mixing ratios of exchanged masses possess a nice structure and the mean exchange probabilities appear to be qualitatively well correlated with a yearly averaged tropopause cut-off probability calculated with ECMWF data.

MIXING OF TROPOSPHERIC AIR INTO THE MID-LATITUDE STRATOSPHERE AND ITS ROLE IN ATMOSPHERIC CHEMISTRY

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During recent years high resolution in-situ observations of a variety of trace gases have been carried out at northern mid-latitudes in the tropopause region in the framework of the Stratosphere Tropopshere Experiment by Aircraft Measurements (STREAM) project. Trace gas and particle distributions in the lowermost stratosphere will be discussed. The dependence of these distributions on season will be shown, including evidence of significant mixing from tropospheric air into the lowermost stratosphere. In addition, implications of these mixing processes for atmospheric chemistry will be demonstrated with results from a three-dimensional Chemistry-Transport Model.

MICROWAVE LIMB-SOUNDING OF WATER VAPOR IN THE TROPOPAUSE REGION

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Microwave limb-sounding is a very promising technique for global measurements of water vapor in the lower stratosphere and upper troposphere. However, the interpretation of data from the tropopause region is not as easy as at higher altitudes. Firstly, the linear approximation is not valid at low tangent altitudes, due to the high water vapor absorption. Secondly, cirrus clouds have an impact on the measurements, which is difficult to model.
We are presenting a case study based on data taken by the Millimeterwave Atmospheric Sounder (MAS) instrument during the ATLAS 1 Space Shuttle mission in March 1992. Care has been taken to separate data with and without cirrus cloud contamination. The cloud information was taken from the Meteosat Cloud Analysis (CLA) data product. The MAS data is compared to the GEOS-1 Multiyear Assimilation Data Set, issued by the Data Assimilation Office at Goddard Space Flight Center. The GEOS data set contains global water vapor fields, four times daily, up to 20 hPa. The comparison indicates that the GEOS data is significantly too high at altitudes above the tropopause.
A comparison of the MAS data with radiosonde measurements available from the UKMO is also presented.

EXPERIMENTAL EVIDENCE FOR THE EXISTENCE OF A VERY LOWERMOST STRATOSPHERE

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The gross transport of tropospheric air into the stratosphere occurs in the tropics through the Brewer-Dobson circulation. Nevertheless, there are also experimental and theoretical findings for the direct impact of the troposphere on the extratropical, lowermost stratosphere in the course of near-tropopause phenomena such as penetrative cumulus convection or small-scale mixing associated with upper level fronts and cyclones. However, little is known on the penetration depth of this direct impact and its geographical variations nor on the persistence of these tropospheric imprints in the stratosphere.
In this paper, we will examine tracer-tracer-correlations from recent measurements in the extratropical tropopause region. These correlations strongly indicate the existence of a direct troposhere-to-stratosphere transport establishing an exchange layer just above the tropopause. The depth of this very lowermost stratosphere varies considerably as a function of the geographical location and exhibits a maximum in the vicinity of the mid-latitude jet stream.

ON THE USE OF THE RDF-TECHNIQUE FOR THE INTERPRETATION OF HIGH-RESOLUTION TRACER MEASUREMENTS IN THE TROPOPAUSE REGION: A CASE STUDY

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Subsynoptic and mesoscale flow features at tropopause levels pre-dominantly occur during stratospheric intrusions. These features are likely to result from the formation of filaments of air masses being either rolled-up or elongated in the presence of a background wind shear. With the recent introduction of model techniques like reverse-domain-filling (RDF) there has been an enormous progress in the modelling of filamentary structures observed by tracer measurements.
In this paper, we will discuss the correspondence between experimental data and the results produced by the RDF-technique on the basis of a detailed case study. For the specific case, rich and coherent subsynoptic mesoscale features has been observed by satellite-borne water vapour images and airborne tracer measurements in the polar frontal region during a strong stratospheric intrusion. It is shown that the potential vorticity reconstructed via the RDF-method reveals filamentary structures that correlates with features seen by tracer measurements not only regarding positioning but also regarding amplitude. Sensitivity studies were carried out to demonstrate the possibilities for the optimization of the RDF-method and the limitations of its applicability.

STRATOSPHERE-TROPOSPHERE EXCHANGES ACROSS THE POTENTIAL VORTICITY BARRIER OF THE SUBTROPICAL JET AS SEEN WITH MOZAIC-OZONE MEASUREMENTS

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The existence and the efficiency of the subtropical potential vorticity (PV) barrier inhibiting the stratosphere-troposphere exchanges between the lowermost extratropical stratosphere and the upper equatorial troposphere are investigated using Measurements of OZone by Airbus in-service AIrCraft (MOZAIC). Among the episodes of high ozone content encountered along MOZAIC flight tracks over Central Atlantic, only those having mixing ratio peak values exceeding 100 ppbv are considered. The ozone episodes that have sub-synoptic to synoptic lengths ($\geq$ 100 km) are all located north of 15-20^{0}N, which corresponds to the mean latitude of the dynamical barrier due to the strong isentropic PV gradient on the cyclonic shear side of the subtropical jet core. Inversely, all the ozone episodes having shorter length scales (a few km to 100 km) are located south of the subtropical barrier within the upper equatorial troposphere. These ozone-rich transients carry ozone mixing ratio that are comparable to that of their isentropic layer when embedded in the lowermost extratropical stratosphere. The occurence of so many ozone-rich transients southward of the subtropical barrier and in such an isentropic layer prompts to revisit our ideas on the efficiency of the barrier against isentropic exchanges and small-scale mixing processes.

LIFE CYCLE OF A TROPOPAUSE FOLD.

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This presentation is a diagnostic study of the whole life cycle of a tropopause fold, from the initiation through the tropospheric fossilization. The case study occured in February 1997 during a shared period of two experimental projects: TOASTE-C (Transport of Ozone and Stratosphere-Troposphere Exchanges) and FASTEX (Fronts and Atlantic Storm Tracks Experiment). The reinforcement of the observations on the eastern coasts of the United States and over the Atlantic Ocean for the FASTEX experiment allowed the initiation phase to be well captured over New Foundland (Canada) by the ARPEGE (Météo-France) global scale analysis system. With guidance based on successive diagnoses derived from the 72-h, 48-h and 24-h forecasts of the ARPEGE model, a french research aircaft (ARAT/INSU) equipped with the Airborne Lidar for Tropospheric Ozone (ALTO) has flown south of Ireland and over the Biscay Bay to sample the tropopause fold before its landfall over western Europe. As expected, lidar observations showed a thin mid-tropospheric layer with ozone mixing ratio about 60-80 ppbv. After documenting the tropopause fold life cycle and discussing the ozone observations, the presentation will finish with perspectives to evaluate stratosphere-troposphere exchange in this case.

THE RADIATIVE CONSTRAINT ON TROPOPAUSE HEIGHT

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The height of the tropopause is determined by a combination of radiation and dynamics. It was proposed by Held (1982, J. Atmos. Sci.) that these effects might be decoupled into radiative and dynamical constraints, each relating the height of the tropopause to the tropospheric temperature lapse rate. A simple model based on Held's radiative constraint was tested by Thuburn and Craig (1996, J. Atmos. Sci.) in a number of experiments using a full atmospheric general circulation model (GCM), and found to give good agreement. Further analysis of the simple model shows the radiative constraint to be a consequence of the fact that the lower stratosphere is close to radiative equilibrium, thereby constraining the tropopause temperature. This understanding of the simple model has been verified directly using a more detailed radiative transfer code, and generalised to predict the dependence of tropopause height on shortwave radiative heating and dynamically-driven vertical motions in the lower stratosphere. These predictions were tested against further GCM experiments which varied the apparent momentum source in the stratosphere.

WATER VAPOUR TRANSPORT ASSOCIATED WITH THE ASIAN SUMMER MONSOON

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This study employs ECMWF Re-Analysis data to investigate the water vapour distribution in the upper troposphere. Water vapour is the primary greenhouse gas and understanding the processes which determine its distribution and transport is crucial. Of special interest is the exchange of water vapour across the tropopause. Our study considers how the Asian summer monsoon affects the moisture budget of the upper troposphere and lower stratosphere. We find that the region of the Asian summer monsoon is a significant moisture source for the upper troposphere outside the deep tropics. Monsoon convection moistens the region of upper level monsoon anticyclone which is located close to the tropopause break where isentropes slope from the troposphere into the stratosphere. An isentropic analysis shows that transport from the troposphere into the stratosphere in this region is normally prevented by strong potential vorticity gradients around the tropopause. However, midlatitude synoptic disturbances occasionally interact with the monsoon anticyclone and pull filaments of tropospheric air off the northern flank of monsoon anticyclone. These filaments, characterised by high values of humidity and low values of potential vorticity, can extend far into the extratropical northern stratosphere. Our case study constructs a 3-dimensional picture of the water vapour transport associated with these filaments, and their interannual variability is investigated.

THE DRY LOWERMOST STRATOSPHERE IN THE ARCTIC WINTER: EVIDENCE FOR LOCAL DEHYDRATION

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Measurements of H_2O have been performed during the Polar Stratospheric Aerosol Experiment (POLSTAR) in January/ February 1997 in Kiruna $20°E\,68°N$ in order to investigate possible condensation processes in the tropopause region of the Arctic. Correlations between water vapour and trace gases as N_2O, CO and O_3 will be shown in this paper and compared to those obtained at different latitude and season. A linear correlation between H_2O and e.g. CO was found in the lower stratosphere for most of the flights. During these flights, the relative humidity was about 25% or less in the lower stratosphere. However, deviations from this correlation found on two days indicate evidence for dehydration in the tropopause region: In these special situations the H_2O mixing ratio was close to or above the saturation mixing ratio. This mechanism might be important to explain the dryer lowermost stratosphere in the Arctic winter compared to other locations and seasons.

VOTALP: OBSERVATION AND SIMULATION OF A STRATOSPHERIC INTRUSION EVENT OVER THE ALPS

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The aim of the VOTALP project (Vertical Ozone Transports over the ALPs) is to study the various aspects of the ozone distribution over the Alps.
One major focus of VOTALP is to study the influence of statospheric intrusions on the ozone at the Alpine peak level. The project combines observations at Alpine peaks, LIDAR measurements at Garmisch-Partenkirchen, vertical soundings and model simulations.
For a special episode in May/June 1996 a stratospheric intrusion crossing the Alps has been analysed. The measurements show an increase of ozone at the peaks in combination with low humidity and high Be7 concentrations. This episode has been simulated with the EURAD model. This model system consists of the NCAR MM5 mesoscale meteorological model (version 5) and the EURAD-CTM chemistry transport model. The model simulations have been performed to study the transport of ozone and stratospheric tracers towards the Alps. Special emphasis is laid on the further fate of the air masses which have entered the middle an lower troposhere under anticyclonic conditions with subsidence. Trajectory and budget calculations will be presented as well as a comparison of simulated and observed data.

RADIATIVE DECAY OF STRATOSPHERIC LAMINAE IN THE TROPOSPHERE

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Sometimes layers of air are observed in the troposphere which are stratospheric in most regards but which are lacking a significant high potential vorticity (PV) signature. It has been suggested that this may be a result of radiation, since radiation affects PV but leaves ozone and humidity unchanged. In this paper, the radiative decay of idealized stratospheric laminae located in a standard midlatitude troposphere is investigated numerically using a realistic radiation scheme. The laminae are characterized by high values of PV with a Gaussian profile in the vertical and corresponding signatures in humidity and ozone. Initially the PV-anomalies decay with a characteristic time scale of a few days, but later the decay slows down considerably. At later times radiative cooling renders the upper part of the laminae convectively unstable. For laminae with finite horizontal extent the change in aspect ratio is studied. The results are compared with those from a simple analytical model, which has been used before in the context of stratospheric filaments.

LIDAR AEROSOL MEASUREMENTS SHOWING THE STRATIFIED STRUCTURE OF THE ANTARCTIC POLAR VORTEX IN THE SPRING OF 1992

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The decay of the Mt. Pinatubo volcanic cloud was monitored from 1991 to 1994 by a ground-based backscatter lidar system implemented at the Antarctic station of Dumont d'Urville (66.4 S, 140 E). During winter and springtime, the location of the station at the periphery of the Antarctic continent allows to sample air inside or outside the vortex within very short periods of time. The aerosols measurements performed in the spring of 1992, a period when the vortex was deformed by planetary waves and slanted with respect to the vertical direction, allow to clearly visualise the stratified structure of the vortex. These observations, analysed in equivalent latitude at various altitude levels will be detailed in the presentation, together with ozone sondes measurements performed in the same conditions. A high resolution PV advection model will also be used to evaluate possible mixing with low latitudes regions in the lower stratosphere.

CASE STUDY OF A CUT-OFF LOW DURING TOASTE-C CAMPAIGN .

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Abstract : The purpose of this work is to evaluate the relative contribution of different processes which can lead to the mixing of stratospheric air initialy contained in a cut-off low into the troposphere. The paper is based on a case-study of a cut-off low that occured during the TOASTE-C campaign in JUNE 1996.

The approach taken is to study the evolution of potential vorticity along trajectories initialised in the low. Ozone measurements by MOZAIC are used to check that the initial and final PV distributions may be compared (i.e. the O3/PV ratio in the stratosphere is similar and the position of PV gradients match those in ozone). Since a decrease of PV along a trajectory can occur through diabatic processes or mixing, 3-D and isentropic 2-D trajectory calculations were compared to ascertain the validity of isentropic assumption.

Having verified this validity, isentropic trajectories were calculated at 310 K and 320 K. Comparisons between ECMWF PV fields and MOZAIC ozone measurements showed that the PV fields on the 14th and on the 22nd of June 1996 were reliable. When comparing PV in the cut-off low on the 14th and on the 22nd, a clear PV decay appears at both levels. Convective erosion seems to be responsible for the mixing at 310 K. At 320 K, the vertical component is less likely to be responsible for the mixing, and a horizontal mixing occuring in the region of the jet seems to be predominant.

MERIDIONAL TRANSPORT OF OZONE IN THE LOWER STRATOPHERE AT MIDDLE LATITUDES: LIDAR OBSERVATIONS AND SIMULATION WITH A HIGH RESOLUTION ADVECTION MODEL

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The observed decrease of ozone during the last 15 years in the middle latitude lower stratosphere is still not well understood. One of the possible causes of decrease is the transport of polar air depleted in ozone which occurs in laminae formed at the edge of the wintertime polar vortex. The signature of such filamentation events as well as the signature of subtropical intrusions are clearly visible in the vertical profiles of the ozone Lidar set-up at Observatoire de Haute-Provence (44N, 6E). A high resolution model of advection of potential vorticity on isentropic surfaces has been developed in the preparation to the European THESEO campaign in 1998/99. The model will be presented and the results of a simulation made for the case of January 1997, where a polar filament and a subtroppical intrusion were successively observed by the ozone lidar, will be shown.

QUANTIFICATION OF LOWER STRATOSPHERIC MIXING PROCESSES USING AIRCRAFT DATA

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Quantitative bounds on the strength of lower stratospheric mixing processes, represented by a vertical diffusivity D are estimated from high-resolution tracer data collected in recent aircraft campaigns. A first approach based on identifying small-scale features and requiring that D be sufficiently small that such features can survive suggests that D can be no larger than $10^{-2}m^2s^{-1}$ and is perhaps considerably less. A second approach based on identifying features that are partially mixed implies a value of D of $1.4 \times 10^{-2}m^2s^{-1}$. Comments will be made on the disagreement between these results and those deduced from radar studies which have suggested a value of D of around $2 \times 10^{-1}m^2s^{-1}$. Some implications for observed tracer spectra will also be discussed.

Analysis of the Seasonal Transport of Ozone and Water Vapor into the Lower Stratosphere

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The composition of the lowermost stratosphere is influenced by both the transport of well aged stratospheric air into the lowermost stratosphere, and the incorporation of fresher air more recently transported through the tropical and subtropical tropopause. Using model analysis, satellite data and chemistry codes the relative importance of these two processes are diagnosed as a function of the time of year in both hemispheres.

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NONHYDROSTATIC NUMERICAL SIMULATIONS AND WIND PROFILERS OBSERVATIONS OF A CUT-OFF LOW EPISODE NEAR THE ALPS

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Strong rainfalls in the Alpine region are often linked to the formation and the stagnation of a cut-off low (COL) near the mountain ridge. In the Mesoscale Alpine Programme (Binder et al., 1995), our concern is to study how the Alps influence the different stages of the life cycle of a COL, and how in return, the COL modify the orographic effects. The available experimental system consists in a meso-scale model and a wind-profilers network. The nonhydrostatic model Meso-NH has a complete package of physical parameterizations and can be coupled with real meteorological analyses or forecasts. The wind-profilers network is composed of five ST radars located in strategic places, offering high-frequency recording of the vertical profiles of the three components of the winds, and of atmospheric reflectivity fields which can be used to estimate the tropopause height. The experimental system is used to investigate a real case of COL formation, issued from the ESTIME experiment (Bertin et al., 1997).

TRANSPORT IN THE LOW LATITUDE TROPOPAUSE REGION AS SIMULATED BY THE UK METEOROLOGICAL OFFICE UNIFIED MODEL

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Two simulations made with the climate version of the UK Meteorological Office Unified Model are presented. It is shown that the model simulation near the tropopause is greatly improved when the number of model levels is increased from 19 to 30. Comparison with Halogen Occultation Experiment (HALOE) water vapour observations shows that the change to 30 model levels not only leads to a better simulation of the zonal mean water vapour distribution, but also improves the simulation of prominent longitudinally varying features. A particularly striking example is the simulation of the region of dry air observed over Indonesia at 100 mb in December - January - February (DJF). These results suggest that the 30 level model version realistically simulates troposphere to stratosphere transport in the tropics. Accordingly, in the second part of this paper we present a more detailed examination of such transport made using idealised model tracers and an off-line trajectory model driven by model winds.

THE MERIDIONAL CIRCULATION IN THE LOWERMOST STRATOSPHERE

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The meridional circulation in the extra-tropics may be classified according to the nature of the eddies which account for the necessary angular momentum transports. According to this classification the circulation in the lowermost stratosphere is an extension of the tropospheric circulation associated with baroclinic waves. Analysis of the structure of these waves relative to the tropopause reveals a surprising result. The zonally averaged circulation in the stratosphere is, on those isentropes which intersect the tropopause, an indirect circulation away from the pole towards the equator. That is, if one averages around the entire isentrope one finds a direct circultion but if one restricts attention to the stratospheric part of the circulation one finds an idirect circulation. The consequences for tracer transport will be discussed.

TRANSPORT SIMULATIONS OF NATURAL TRACERS WITH THE ECHAM GCM: SENSITIVITY OF STRATOSPHERE–TROPOSPHERE EXCHANGE TO THE VERTICAL RESOLUTION

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The global distributions of SF_6 and ^{14}C from above-ground nuclear weapon tests have been simulated with two versions of the atmosphere general circulation model ECHAM: the standard version with 19 layers and a vertical resolution of approx. 2 km in the tropopause region and a modified version with the same model top, but 39 layers and about 1 km vertical resolution. Both trace substances are of anthropogenic origin and long-lived. SF_6 is emitted continously at the surface, whereas bomb produced ^{14}C has been introduced rather instantaneously in the northern hemispheric stratosphere. Because of their different source regions, this tracer pair represents a suitable combination for evaluating vertical transports in either directions. The models' transport characteristics are analysed with regard to stratosphere-troposphere exchange in terms of adjustment times. The simulation results are compared with observed concentration distributions.

SIMULATION OF A STRATOSPHERIC INTRUSION EVENT AT SUBTROPICAL LATITUDES USING A COUPLED CHEMISTRY-GENERAL CIRCULATION MODEL.

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An important source of O_3 in the troposphere is downward transport from the stratosphere through tropopause foldings associated with large scale cyclogenesis, cut-off lows and quasi-adiabatic transports along isentropic surfaces at mid-latitudes. Stratosphere-troposphere exchange (STE) processes co-determine the distribution of O_3 in the troposphere, and knowledge of its influence on tropospheric O_3 levels is necessary to assess the climate effects of O_3 perturbations due to human activity. A tropopause folding event associated with the development of a cut-off low over southeastern Europe at the end of March 1995 enhanced the ozone concentrations in the upper troposphere. The episode has been simulated using a coupled chemistry-GCM that has been 'nudged' towards actual meteorology using a simple four-dimensional assimilation technique based on ECMWF data. The GCM used is the European Centre Hamburg Model, version 4 (ECHAM-4). Results of the model run are compared with observational and analysed meteorological data. In particular, simulated geopotential heights show a realistic representation of the synoptic development of the cut-off low system. The model also successfully reproduce the space-time evolution of potential vorticity and specific humidity fields associated with the tropopause fold. Furthermore, modelled O_3 concentrations during that period show a pronounced increase in the upper troposphere associated with downward fluxes from the stratosphere. The good qualitative (and in many cases quantitative) agreement between the simulated and observed stratospheric intrusion event shows that the model provides a useful tool to analyse stratosphere-troposphere exchange processes and their effect on the tropospheric ozone budget.

Transport and mixing of a long-lived stratospheric intrusion in the upper troposphere.

Ground-based lidar measurements of ozone and aerosol profiles above Fritz Peak Observatory near Boulder, Colorado (40N,105W) are used in conjunction with radiosonde profiles and satellite water vapor imagery to characterize the structure of a dry, ozone-rich streamer of stratospheric air that appeared in the upper troposphere over the western United States on June 30, 1997. The streamer remained intact through more than six hours of observations before being rapidly dissipated through convective mixing induced by the incursion of a moist subtropical air mass between the streamer and the convective boundary layer. Potential vorticity analyses and isentropic back trajectories are used in conjunction with water vapor imagery to show that the streamer evolved from a stratospheric intrusion that took place approximimately 10 days earlier and more than 8,000 km from Colorado above East Central Asia.

ANALYSIS OF TRANSPORT AND EXCHANGE PROCESSES IN THE TROPOPAUSE REGION BY MEANS OF LAGRANGIAN METHODS

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This paper is focusing on Lagrangian studies of the dynamical processes in the tropopause region. A case study is presented analysing air mass transport within a trough and a streamer developing therefrom in February 1997. The episode was simulated using the EURAD model system designed for mesoscale meteorological and chemistry transport simulations. The air mass flow was analysed by two Lagrangian methods – contour advection and trajectory analysis – which are implemented as postprocessors of the meteorological model MM5 in the EURAD model system. The results of the contour advection studies are compared with measurements carried out during a Transport of Ozone and Stratosphere–Troposphere Exchange (TOASTE) campaign on February 4 and 5, 1997. The Airborne Lidar for Tropospheric Ozone (ALTO) flown on the French Fokker 27 measured thin ozone rich layers in the free troposphere the origins of which were determined by the use of contour advection. For quantitative estimates of stratosphere–troposphere exchange the analysed area was embedded in a three–dimensional box covering the upper troposphere and lower stratosphere. 21000 forward trajectories were released within the box and potential vorticity and temperature were calculated along the trajectory path. Thereby we can determine whether the air parcels have crossed the tropopause. The results of these flux estimates are compared with results of Eulerian calculations (budget calculations and Wei's formula).

A CRITERION FOR THE FORMATION OF FILAMENTS AROUND THE POLAR VORTEX.

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The study of Lagrangian accelerations in geophysical turbulence allows to partition the fluid into regions with different dynamical properties (B.L. Hua and P. Klein, Physica D, 1997). The partition is based on the eigenvalues of a linear operator, describing the evolution of particle dispersion or of tracer gradients. The analysis is applied here to diagnose the formation of steep gradients and the generation of filaments around the polar vortex in the stratosphere during two study periods in January 1992 and February 1995. By comparing with contour advection calculations, it is shown that the eigenvalues can be used as a predictor of the formation of filaments on the boundary of the vortex.

THE RELATIONSHIP BETWEEN THE EXCHANGE ACROSS THE SUBTROPICAL BARRIER AND PLANETARY WAVE ACTIVITY IN A GLOBAL MODEL.

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The exchange of air from the tropics into midlatitudes across the stratospheric subtropical barrier is investigated in terms of potential vorticity fields on isentropic levels in a global 3–d mechanistic gridpoint model.
Vacillations of the planetary wave activity are caused by the two concurrent effects of a steady state forcing at the lower boundary at 200 hPa with observed geopotential height climatologies, which pull the model away from the zonal mean initial state, and by the Newtonian Cooling parametrization of diabatic heating, which relaxes the model temperatures to the zonal mean radiative equilibrium temperature.
In order to investigate the behaviour of the stratospheric subtropical barrier under different climatological situations, we have performed two 1000 day model simulations with an 'ENSO (EL Niño/Southern Oscillation) cold' and an 'ENSO warm' forcing at the lower boundary. The overall evolution of the model stratosphere is in accord with the observations of ENSO cold and ENSO warm years. Exchange events across the subtropical barrier always occur during periods with large wave activity.

SPATIAL AND TEMPORAL VARIABILITY OF TROPOPAUSE FOLDS OCCURENCE - IMPLICATION FOR THE CROSS TROPOSPHERIC OZONE FLUX

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A climatology of tropopause folds has been established by using two data sets of together more than 10000 vertical ozone, temperature, relative humidity and wind profiles. The profiles were obtained either by ozone/radiosoundings (made available by WODC) and by in-situ measurements on commercial aircraft (MOZAIC project). An automatic detection algorithm for tropopause folds was developped and validated by extensive meterorological analysis. We found that folds were more abondant over North America (10 % of the soundings) than over Japan (7%) and Europe (4%). Also within continents, strong spatial differences were encountered. Another interesting result was that the folding occurrence showed a significant positive trend over North America and over Europe, more folds being detected especially in the nineties. An attempt will be made to correlate these results with climatolgies of other meteorological parameters / tracers (e.g. cyclone occurrence, ...). The fold occurrence was combined with litterature estimates of the ozone amount transfered in single events. in order to derive the regional and northern hemispheric ozone flux across the tropopause.

TRANSPORT IN THE MIDDLE ATMOSPHERE (MA) ECHAM GENERAL CIRCULATION MODEL

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The simulation of the large scale transport in the MA/ECHAM general circulation model is evaluated by analyzing the multi-year and three dimensional evolution of two tracers: SF6, a tracer with specified sources at the surface, linearly increasing with time, and a C14 tracer cloud, initialized in the polar lower stratosphere. The MA/ECHAM model is the middle atmosphere version (surface to 0.01 hPa) of the ECHAM4 general circulation model. Among novel aspects, the MA/ECHAM model includes a parameterization of the effects of a continuous spectrum of gravity waves. The MA/ECHAM model will be used in simulations including active feedbacks with chemical models, one motivation for first evaluating its passive tracer transport. Given that the MA/ECHAM model include the middle atmosphere, it is possible to investigate the role of the large scale residual circulation encompassing the middle atmosphere on the stratosphere-troposphere exchange.
Availability of several observations of SF6 and C14 concentrations allows a comparison with the simulation results. The characteristics of the upward transport in the model are elucidated by the temporal evolution of the SF6 tracer. It is shown for instance that most of the upward transport is occurring in the tropics and therefore a meridional gradient in the SF6 tracer concentration develops along the 400 K isentrope. From the analysis of the C14 tracers it is possible instead to deduce the location and seasonality of the downward transport.

PSEUDO-CONTOUR ADVECTION WITH SURGERY.

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Contour advection is frequently used to reconstruct small-scale structures of potential vorticity or tracers on isentropic layers. The main assumption of this method is that the evolution of the field remains purely adiabatic over a finite integration time. We present a modified version of contour advection in which large-scale information, collected either from operational weather analysis or from satellite measurements, can be included. The modification introduces a large-scale pseudo-velocity which moves the contour in order to preserve the large-scale constrains provided by the observations, and generates new contours when required. The new algorithm can be used in an on-going assimilation procedure unlike standard contour advection which is applied as a series of initial value problems. The method will be demonstrated on a idealized case. We hope to present also results on the formation of the O_3 collar around the southern hemisphere late winter polar vortex.

COMPARISON OF RDF WITH IN-SITU DATA

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Over the last few years there have been an increasing use of two trajectory techniques (Contour Advection and Reverse Domain Filling (RDF) Trajectories) to assist in the visualization of flows. Although the initial motivation for this work came from dynamical studies of simple model atmospheres. The technique has been applied with qualified success to a number of real atmospheric situations where more or less reliable large scale dynamical wind fields are available. The outcome of these studies have been mixed with some studies concluding that they are at best qualitative while other studies have shown apparantly remarkable agreement. In this talk the RDF technique will be used to 'reconstruct' a PV distribution at high resolution that contains structural feature of similar scale to insitu aircraft observations. Under some circumstances encouraging agreement is obtained between structures in the aircraft observations and features in the reconstructed PV. Reasons for the agreement and disagreement will be discussed.

OBSERVATIONS OF TRACE GASES IN THE VICINITY OF A TROPOPAUSE FOLD

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Tropopause folds are one of the final steps in the transport and modification of air from the tropics to northern latitudes through the stratosphere. Classical tropopause fold studies concentrate on the flux of dry ozone rich air from the stratosphere into the troposphere. In this study we will present composition measurements of ozone and condensable vapours such as water vapour. Evidence will be presented that indicates the nett transfer of water vapour into a tropopause fold giving the possibility that although in fold events the main transfer is from the stratosphere to the troposphere there may be a reverse flux of moisture (but not air) from the troposphere into the stratosphere. Further evidence for the existance of such processes will be discussed.

ON THE ADVECTION OF HIGH RESOLUTION TRACERS BY LOW RESOLUTION WINDS

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Recently Lagrangian techniques have been employed to study the global transport of atmospheric chemicals. Large scale strain tends to dominate the appearance and positioning of tracer filaments so that tracers simulated using coarse-grained wind fields to integrate the trajectory equation closely resemble those simulated using the highest resolution analyses available. Here. it is shown that although contour stretching rates are very insensitive to the spatial truncation of the wind field the displacement errors in filament position are sensitive. A quantitative lower estimate is obtained for the tracer scale factor (TSF); the ratio of the smallest resolved scale in the advecting wind field to the smallest width above which all filaments are accurately positioned by a contour advection (CA) simulation. For a baroclinic wave life cycle the TSF=6.1 ± 0.3 whilst for the NH wintertime lower stratosphere the TSF=5.5 ± 0.5. Uncertainty in contour initialisation is investigated for the stratospheric case. The effect of smoothing initial contours is to introduce a spin-up time, after which wind field truncation errors take over from initialisation errors (2-3 days). It is also shown that false detail from the proliferation of fine-scale filaments limits the useful life-time of such CA simulations to 7-10 days.

DYNAMICS AND TRANSPORT IN THE LOWER STRATOSPHERE

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This talk will comprose an overview of recent developments in our understanding of lower stratospheric dynamics and transport. The gross mass flux across isentropic surfaces is associated with the diabatic circulation, which in middle latitudes is now recognized as being driven by waves through the "extratropical pump" mechanism. However, the observation that upwelling is concentrated in the tropics is somewhat perplexing, given that, if wave breaking is confined to the midlatitude surf zones, and the stratosphere is linear and inviscid, upwelling would concentrate at the subtropical edge of the surf zone. Relevant results from a zomally symmetric model will be described.
Observations of lower stratospheric tracers will be interpreted, with the aid of a "leaky tropical pipe" model of the stratosphere, to put constraints on our understanding of transport across the key transport barriers—the subtropical edge, the tropical tropopause, and the midlatitude tropopause.

STUDY OF STRATOSPHERE TROPOSPHERE EXCHANGE AT HIGH LATITUDES WITH MST RADAR AND OZONESONDES

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The ESRAD MST radar, located at Esrange (68°N, 21°E), made continuous measurements of winds and layering structure in the troposphere and lower stratosphere during the entire winter 1996/97, and will continue to make measurements during the winter 97/98. One of the many atmospheric features which are detected by the radar is the tropopause and the layer of lowermost stratospheric air just above the tropopause, which give distinctive signatures in altitude profiles of radar echo power. On several occasions during the winter of 1996/97 the radar tropopause over Esrange was observed to branch. Using meteorological maps and ozone sondes we show that most such ESRAD features also correspond to frontal zones. Comparison with ozonesondes also shows that the weak and low tropopause in a trough can be identified with the MST radar. However, on a number of occasions a region of enhanced radar echoes extending from a trough corresponded to regions of stratospheric air (high ozone content / low humidity) as identified by ozonesondes. It therefore seems possible to monitor the stratospheric intrusion with the radar, if it can be identified as a stratospheric airmass with ozonesonde data. Results from such combined radar - ozonesonde measurements during the the winters 96/97 and 97/98 will be presented.

STRATOSPHERE-TROPOSPHERE EXCHANGE WITHIN A CUT-OFF LOW: AIRBORNE MEASUREMENT CAMPAIGN AND MESOSCALE MODELLING

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In June 1996, a Transport of Ozone and Stratosphere-Troposphere Exchange (TOASTE) campaign was set up to study the evolution of a cut-off low system after its removal from the general circulation. The Airborne Lidar for Tropospheric Ozone (ALTO) was flown on the French Fokker 27 research aircraft. Ground based measurements and radiosondes are also available. The use of an aircraft allows us to follow the system for several days and many two-dimensional ozone and aerosol backscattering coefficient vertical cross-sections through it are available. The observed decay of the cut-off low is investigated in association with the question of irreversible transport. The use of a meteorological mesoscale model (MM5) helps us tackling the question of diabatic erosion as a possible transfer mechanism. This turns out to take place mostly on the eastern flank of the cut-off low. Ozone filaments are also observed and the model ability to account for the measured ozone structures is also investigated. Specifically, the question of the best corresponding modelled quantity is raised. Potential vorticity is not the only useful one: more attention should be paid to the dry layers generated by the model.

Chemical impact on the troposphere of tropopause fold events during TOASTE campaigns.

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Tropospheric ozone is an important greenhouse gas and atmospheric oxidant, playing a key role in the composition of the troposphere. There are two primary sources of tropospheric ozone: downward flux of ozone from the stratosphere into the troposphere, and the photo-oxidation of ozone precursors from anthropogenic and natural sources.
We have developed a tropospheric chemical transport model, TOMCAT, with meteorology forced by ECMWF analyses. The model contains a detailed description of tropospheric chemistry. Stratosphere-troposphere exchange (STE) events in March 1995 and June 1996 have been studied during the TOASTE-B and C (Transport of Ozone And Stratospheric Tropospheric Exchange) campaigns. We compare these observations with TOMCAT.
The importance of STE on the tropospheric distribution of chemical trace species is discussed.

MIXING BETWEEN STRATOSPHERE AND TROPOSPHERE STUDIED WITH NCAR/CCM3

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We have used the winds and thermal structure obtained from a simulation with NCAR/CCM3 General Circulation Model to advect parcels in an isentropic offline model. A number of calculation have been performed with parcels initialized on different θ surfaces, from 330 K to 400 K. This range of θ's spans the lower-most stratosphere. Using isentropic potential vorticity, we have been able to distinguish air of tropospheric nature from stratospheric air. Parcel calculations were performed in different seasons to study the variability of mixing. Calculations in which the parcels were initialized on θ surfaces intersecting a large part of the tropical troposphere have shown that, in the presence of synoptic disturbances at mid-latitudes, mixing is an efficient process that produces substantial lateral exchange of air masses. At higher latitudes. sinking is a more prominent feature. In order to provide a quantitative estimate of the mixing. we have calculated horizontal diffusion coefficients from the dispersion of air parcels about their "center of mass".

A CASE STUDY TO IDENTIFY LAYERS WITH LAMINAR OR TURBULENT FLOWS USING ST RADAR AND RADIOSONDE OBSERVATIONS AND TRAJECTORY CALCULATIONS

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Continuous tropo/stratospheric investigations of the polar atmosphere have been carried out with the ALOMAR SOUSY radar (53.5 MHz) in Andenes, Norway (69° N, 16° E) during the winters 1995/96/97. The radar measures wind and static stability (or power) profiles, and are used together with high-resolved radiosonde soundings to track the evolution of these parameters as air masses with low or high PV crosses the site. Trajectory calculations provide information on the origin of the layers derived from radar and radiosonde signatures.
In addition, the wind profiles obtained by radar and radiosonde can be used to identify gravity waves, and their potential contribution to lamina formation will be evaluated.

INVESTIGATING TRANSPORT ACROSS THE TROPOPAUSE.

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Observations of chemical tracer show a sharp contrast across the tropopause. It therefore appears that the tropopause may act as a barrier separating two well mixed regions, analogous to the polar vortex edge in the lower stratosphere. Isentropic advection studies are used to investigate this barrier and to quantify its leakiness.
Particle and contour advection studies have often been used to quantify transport via stretching rates. However, the results of these diagnostics have been somewhat ambiguous in the case of the tropopause. It is argued that problems arise because the tropopause is a highly asymmetric and leaky barrier. An alternative diagnostic has been used to overcome these difficulties by calculating an effective diffusivity as a function of an equivalent latitude coordinate defined in terms of the area within tracer contours, following Nakamura (1996: J. Atmos. Sci., 53, 1524). Observed velocities from isentropic surfaces intersecting the tropopause are used to advect tracer and the effective diffusivity is calculated as a diagnostic from the tracer field. A clear minimum in effective diffusivity is seen and it is proposed this should be identified as the tropopause. The relation between this and more conventional definitions of the tropopause, e.g. defined in terms of particular values of potential vorticity, is discussed.

THE RESIDUAL MEAN MERIDIONAL CIRCULATION IN THE LOWER STRATOSPHERE, DIAGNOSED FROM 15 YEARS OF ECMWF-REANALYSIS DATA

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In the lower stratosphere the mean trajectories of air parcels form one meridional cell in each hemisphere, with upward motion in the tropics, poleward flow at middle latitudes and downward motion into the troposphere at higher latitudes. This Lagrangian-mean circulation can be approximated by the transformed Eulerian mean (TEM) circulation, which is the Eulerian mean circulation in which the part forced by eddy heat transport is removed.

The TEM circulation can be obtained from meteorological analyses as produced by numerical weather prediction (NMP) models. The required circulation data, particularly the vertical velocity, are, however, sensitive to the formulation of the model. Therefore, the TEM circulation diagnosed for a period of several years might show spurious jumps due to changes in the model during that period. This problem, however, can be overcome by using reanalysed data that for the whole period are produced by one (state-of-the-art) version of the NMP-model.

In this study the TEM circulation in the lower stratosphere is diagnosed from 15 years (1979-1993) of ECMWF-reanalysis data. Results will be presented for the height and latitudinal dependence of the circulation, as well as for its seasonal and interannual variability.

OBSERVATIONS OF THE TROPOPAUSE REGION ABOVE ANDENES DURING THE BREAK UP OF THE POLAR VORTEX IN MARCH 1995 WITH THE ALOMAR SOUSY RADAR

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The ALOMAR SOUSY radar, operating on 53.5 MHz at Andenes (69.3°N, 16.0°E), has performed continuous tropo/stratospheric observations from January through March 1995 using the Doppler beam swinging (DBS) technique. The radar measures wind and reflectivity profiles with 300 m range resolution and 5 min time resolution, in addition, a radar tropopause height and vertical momentum fluxes are derived. The variability of the tropopause region was investigated in detail during the break up of the polar vortex in March 1995. During the passage of an anticyclone south of Andenes the radar observes strongly enhanced zonal and meridional wind velocities at tropopause heights between 10 and 11 km. The passage of the jet is connected with enhanced wave activity above the tropopause as indicated by vertical momentum fluxes. On the following days a decrease of the tropopause height by about 3 km was detected and wave activity was not present. The estimated radar tropopause height is in good agreement with balloon soundings.

OZONE-RICH TRANSIENTS IN THE UPPER EQUATORIAL ATLANTIC TROPOSPHERE

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High concentrations of ozone are found in the Earth's stratosphere, but strong stratification suppresses efficient exchange of this ozone-rich air with the underlying troposphere. Upward transport of tropospheric trace constituents occurs mainly through equatorial deep convective systems. In contrast, significant downward transport of ozone-rich stratospheric air is thought to take place only outside the tropics by exchange processes in upper-level fronts. Ozone within the tropical troposphere is assumed to originate predominantly from ground-based emissions of ozone precursors rather than from a stratospheric source. Recent measurements of ozone in the upper troposphere in convective regions over the Pacific Ocean indeed reveal near-zero concentrations. Here we present sharply contrasting observations: ozone-rich (100–500 parts per billion by volume) transients were frequently encountered by specially equipped commercial Airbus 340 aircraft (MOZAIC project) at a cruising altitude of 10–12km in the vicinity of strong convective activity over the equatorial Atlantic Ocean. This strongly suggests that the input of stratospheric ozone into the troposphere can take place in the tropics. We suggest that this transport occurs either by direct downward movement of air masses or by quasi-isentropic transport from the extratropical stratosphere.

STRATOSPHERE-TROPOSPHERE EXCHANGE IN A STRATOSPHERIC INTRUSION

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The so-called "advection method" for calculating stratosphere-troposphere exchange (STE) has been refined in order to be able to calculate mass exchange also in the case of a multi-folded tropopause. STE was calculated from a numerical simulation of the heavy precipitation event which occurred from 5 to 7 November 1994 in the southern Alps. It was instigated by a pronounced stratospheric intrusion. The investigation aimed at isolating the contribution of each diabatic and turbulent process on the mass exchange at the tropopause. For this, the tendencies of momentum and temperature due to the various physical processes were stored together with normal output during the model run. The full 3-dimensional potential vorticity tendency equation could then be solved and the mass exchange at the PV-defined tropopause calculated. Results show the dominant role of horizontal diffusion of momentum and temperature for STE which is much larger than the contribution of vertical mixing. Other processes like moisture physics and radiation vary strongly through the life cycle of the stratospheric intrusion. The results highlight the strong dependence of STE on the representation of physical processes in a mesoscale model.

STRATOSPHERIC–TROPOSPHERIC–EXCHANGE: A PINATUBO CASE STUDY

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Stratospheric–tropospheric exchange (STE) processes are one of the major problems of the 3d transport simulations with general circulation models. The simulation of the STE in the tropical lower stratosphere is especially crucial. The volcanic eruption of Mt. Pinatubo, in June 1991, had not only significant impact on stratospheric and tropospheric climate and circulation, it is also a natural phenomenon which enables us to better understand STE processes, especially in the tropical region. For the Pinatubo period (1991 –1993) a large amount of observations exist, which offer a unique opportunity to verify and to test the representation of the STE and the 3d transport in a global model. In using different versions of the Hamburg climate model ECHAM4: ECHAM4_L19, ECHAM4_L39(DLR), MA/ECHAM4 (L39,L69), we performed a set of Pinatubo simulations with prognostic aerosol. Here we present results of these different numerical experiments for the years 1991 and 1992 and comparisons with satellite data and in situ measurements at different stations. It will be shown that both a fine model resolution in the tropopause region and a high top of the model atmosphere are necessary to adequately represent the observed transport characteristics of a major volcanic eruption. The importance of an interactive treatment of the volcanic cloud will also be evidenced.

DIAGNOSING EXTRATROPICAL STRATOSPHERE-TROPOSPHERE EXCHANGE: A CASE STUDY

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The chemistry and the distribution of trace gases in the lowermost stratosphere cannot be understood without a quantitative knowledge of the synoptic (and smaller) scale transport between stratosphere and troposphere. In this paper several different methods to diagnose the synoptic-scale stratosphere-troposphere exchange are applied and compared to each other in the framework of a case study. A case with strong convective heating in a decaying cut-off cyclone is selected. A consistent data set is obtained through a special ECMWF-model run with standard resolution, but enhanced output storage. Despite the strength of the cross-tropopause mass exchange during the episode the different diagnostic methods yield quite different results. In particular some of the more popular methods based on Wei's (1987) formula have to be treated with care. Intercomparison of the different methods helps to understand some of the problems.

SEASONAL VARIATION OF STIRRING AND MIXING IN THE LOWER STRATOSPHERE

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Mixing processes in the lower stratosphere are examined using trajectory calculations, in-situ trace gas observations, and a simple strain-diffusion model. The quasi-horizontal stirring and generation of filamentary structures by the large-scale flow is examined by performing trajectory calculations driven by analysed winds. These calculations are used to calculate the rate of reduction in scale, and orientation, of filamentary structures. High-resolution trace gas measurements from the series of NASA ER-2 aircraft campaigns (which span the different seasons) enable the fine-scale structure of filaments to be examined. Also, tracer-tracer scatter plots can be used to identify partially mixed filaments. The trajectory calculations and aircraft observations are used together with a 1-D strain diffusion model to quantify the mixing of filaments; in particular, the effective diffusivities and "mix-down" time of the filaments are estimated. Calculations during winter/spring indicate that the time scale for horizontal scales of 1000 km to be reduced to mixing scales is around 10 to 15 days, and that complete mixing occurs within a month. However, preliminary analysis of summer conditions suggest that there is much weaker stirring and mixing, and that the mix-down time of filaments is longer than 2 months.

CASE STUDY OF STRATOSPHERE TROPOSPHERE EXCHANGE USING VHF WIND PROFILER, OZONESONDE, RADIOSONDE AND E.C.M.W.F. DATA.

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Recent results, including some from European campaigns CWINDE (COST Wind Initiative for Network Demonstration in Europe) and FASTEX (Fronts and Atlantic Storm Tracks Experiment), are used to examine a stratosphere-troposphere exchange event on 8-9 March 1997, where ozonesonde and radiosonde data indicate an intrusion of dry, stable, ozone-rich air as low as 3 km altitude above Aberystwyth. Data from the VHF radar at Aberystwyth are employed, with the dependence of radar echo power on humidity investigated statistically using output from January-March 1997. VHF echo power is found to be reduced for both dry and saturated air; nevertheless, layers in the echo power structure associated with dry stable air can be tracked. ECMWF analyses of trajectories and potential vorticity fields will also be presented.

EVALUATION OF THE SEASONAL CYCLE OF WATER VAPOR IN THE STRATOSPHERE DERIVED FROM MONTHLY AVERAGE TROPICAL TROPOPAUSE TEMPERATURES USING A CO PHOTOCHEMICAL CLOCK

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In situ measurements taken on the NASA ER-2 aircraft during the STRAT campaign during 1995 and 1996 included a series of dives in the tropical lower stratosphere. With a simple photochemical model, observed CO profiles provide a measure of the photochemical age of the air in the stratosphere. Using this age as the transit time of the airmass from the tropical tropopause to its measured altitude, we compare measured CO2 and water vapor mixing ratios with entry-level mixing ratios corresponding to the date the air mass crossed the tropical tropopause. These comparisons demonstrate that water vapor saturation mixing ratios derived from monthly-averaged radiosonde temperatures at the tropopause between 10S and 10N represent the boundary condition for water vapor reasonably well. We also demonstrate that most of the disagreement between boundary condition mixing ratios and measured values is a result of the mixing of midlatitude air. Ascent velocities in the tropical lower stratosphere determined from plots of photochemical age vs. potential temperature will also be presented.

AIRBORNE CO_2, CH_4, O_3, AND SF_6 MEASUREMENTS TO STUDY TRACER TRANSPORT AROUND THE TROPOPAUSE

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Whole air samples to measure the mixing ratios of carbon dioxide, methane, ozone, and sulfur hexafluoride were collected around the mid- and high-latitude northern tropopause in the winter months (December to April) 1993/94 and 1994/95. The samples originate to the same part from the upper troposphere, mainly from the 400 hPa pressure level, and from the lowermost stratosphere up to altitudes of 12 km. By evaluating potential temperatures of the examined air parcels and derived trace gas - trace gas correlations, three types of tropospheric air masses could be distinguished: mid-latitude, polar, and arctic air. As confirmed by isentropic back trajectory calculations, the mid-latitude upper troposphere was frequently suffered by polluted air from the low troposphere resulting in a positive correlation of CH_4, SF_6, and O_3. In contrast, in the high-latitude upper troposphere as well as in the lowermost stratosphere, first, the encountered air masses were better mixed, and second, both CH_4 and SF_6 were negatively correlated with O_3. Furthermore, caused by the actual strong SF_6 growth rate of nearly 7% per year, the age of the observed air masses since their entry into the stratosphere could be inferred. This SF_6 - age was surprisingly high, e.g. around two years in an altitude of 11.5 km and thus just 3 km above the local dynamical tropopause.

A SUMMER STRATOSPHERIC INTRUSION EVENT AT JUNGFRAUJOCH (3,580 M ASL) IN SWITZERLAND

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Very high ^{7}Be activity concentrations (>11 mBq/m^3 at STP) were recorded at Jungfraujoch in the Swiss Alps from 16 to 23 July 1996. In addition, half-hourly ozone concentrations exceeded 80 ppbv on 19 and 20 July 1996. The synoptic pattern at the 500 hPa level revealed an eastward-moving upper trough-ridge system over North Atlantic and Scandinavia. Vertical SW-NE cross-sections of isentropes indicated a low tropopause over Scandinavia on 17 July. Time-height plots of temperature, potential temperature, y-axis (north-south) kinetic energy, specific humidity and ozone from the aerological soundings at Payerne all suggested that the high ^{7}Be and ozone levels were associated with a stratospheric intrusion event above the northern Atlantic-Scandinavia region, followed by anticyclonic subsidence and strong advection to the Jungfraujoch. Ensembles of kinematic 3-D back-trajectories calculated from ECMWF analyses, arriving at Jungfraujoch on 19 and 20 July, were found to be consistent with the observations. Although, the original stratospheric intrusion occurred more than one thousand kilometres away from Jungfraujoch, it was, nevertheless, able to enhance both ^{7}Be and ozone concentrations at the site. The study was carried out within the EU project "VOTALP" (Vertical Ozone Transport in the Alps).

OA15 Clouds and their impact on radiation and photo-chemical processes

Convener: Raschke, E.

01 Remote sensing of clouds and aerosols

Convener: Raschke, E.

INVESTIGATION OF THE ERROR IN DERIVED MEAN CLOUD COVER FOR A PROPOSED SPACE-BORNE CLOUD RADAR

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Both NASA and ESA propose a space-borne cloud radar, in sun-synchronous orbit, to provide both a cloud climatology and a study of cloud processes. One product from the mission will be 3D monthly mean cloud cover over a global grid. However, this will be only an estimate of the true mean due to the incomplete space-time sampling of the averaging boxes. A study is conducted into this sampling error. It is found using simulated overflights of the ISCCP cloud dataset that this error is independent of equator crossing time, repeat period and month studied and varies little with increasing swath width. The ISCCP dataset has a very coarse space-time resolution and as a result overflight simulations of GMS data for a set of 15 regions were also conducted. This was found to give an error smaller than that derived from the ISCCP dataset being less than 10% for means over 250km boxes irrespective of orbit and swath width. In both of the above studies the estimates in the error was that in 2D cloud cover. The GMS data was also used to investigate errors in derived 3D cloud cover by associating a height with the cloud top temperature and by making various assumption about cloud overlap in layers obscured by those above. It was again found that the error in 3D cloud cover was less than 10% irrespective of the overlap. These studies assume perfect retrieval at points observed by the radar whereas it is possible that the radar may not detect all clouds. This could lead to biases in estimates of instantaneous cloud cover that are larger than the sampling error if the cloud radar data is integrated for a long time to improve cloud detection. However, simulations using reflectivities drawn at random from EUCREX data found that this bias could be removed if a minimum detection threshold is used. This threshold is independent of cloud cover.

HORIZONTAL INHOMOGENEITIES IN CLOUDS AND THEIR EFFECT OF REMOTE PARTICLE MEASUREMENTS

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Major cloud fields are horizontally inhomogeneous even on spatial scales which are compatible with the resolution of current satellite imaging systems. Thus estimates of particle sizes as obtained from multispectral satellite-borne imaging data are biased by such inhomogeneities whose origin are mostly iinternal convections but also travelling waves.
This paper presents the evidence of inhomogeneities onthe basis of airborne particle measurements inside of cirrus and of stratus fields and also by numerical simulations with a nonstationary mesoscale atmospheric circulation model. The latter determines for each grid area and time step the particle spectrum inside of clouds simulating most known microphysical processes. Estimates of the affect of such horizontal inhomogeneities on satelliteborne retrievals are given.

CLEAR AND CLOUDY SKY CASE STUDIES OF O_4 AND OXYGEN A-BAND ABSORPTIONS AS SEEN BY GOME.

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Using the DOAS-technique (Differential Optical Absorption Spectrometry), the O_4 and O_2 A-Band absorption as detected by GOME were investigated for different clear and cloudy sky conditions. The retrieved total amounts of O_2 and O_4 were used to derive an apparent cloud top height and the additional geometrical pathlength caused by Mie scattering inside the cloud and multiple scattering between patches of clouds.
The derived cloud top heights for GOME observations over the Rhein/Main area (Germany) are compared with the meteorological reports provided by the DWD (Deutscher Wetterdienst) and the DFS (Deutsche FlugSicherung GmbH, from aircrafts commuting with the Frankfurt airport). These findings will be presented.

IMPROVED CORRECTION OF THE VISIBLE CHANNEL FOR SATELLITE BASED CLOUD CLASSIFICATION

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The visible channel is important in separating clear sky and cloudy pixels and evaluating cloud thickness. But for different illumination conditions the reflectance of the surfaces (land, sea, clouds) can vary therefore it is difficult to compare consecutive images or different areas of the same image. The usual homogenisation procedure (dividing the reflectances by the cosine of the solar zenith angle and normalising to a constant angle) overestimates the reflectances for high solar zenith angles due to anisotropy effects. We used the Modtran3.5 radiative transfer model for simulating reflectances for cases representing all the illumination conditions (considering satellite zenith angle and relative azimuth angle as well) detailed enough for a further linear interpolation. We used different built in cloud models of Modtran. After the simulations we integrated the radiances with filter functions of different satellite detectors. The validation was made with NOAA 12, Meteosat and ERB measurements. We had some difficulties for a limited range of the illumination conditions (forward scattering close to the sunglint case) which might be neglected for the Meteosat B format but will become important for further GOES and NOAA applications. We produced correction tables from the simulations by linear interpolation which can be used directly to measured radiances. At the moment we use this correction method for the preoperational cloud classification of Meteosat images which was the principal aim of the study.

ESTIMATION OF CIRRUS AND MULTY-LAYER CLOUD PARAMETERS FROM MULTISPECTRAL MEASUREMENTS IN THE NEAR-INFRARED

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Spectral measurements in the near-infrared region can be used to infer cloud optical depths τ and effective particle sizes r_{eff}. In this study measurements with the spectrometer OVID from four flight missions above ice cloud fields during EUCREX'94 were analyzed and compared to simulations. Optical characteristics of ice crystals have been calculated with a ray tracing model for a huge number of different particle shapes and sizes. Without information from a second viewing angle a particle shape has to be assumed, based on plausible reasoning. Assuming such a particle shape two window channels with different ice absorption are sufficient to determine r_{eff} and τ. An excellent correspondence is found in comparison with the results derived from independent remote sensing instruments, as well as from in-situ measurements.

Multiple cloud layers were observed commonly troughout much of the cirrus missions of EUCREX 94. The measured spectral features can be well described by simulations of a water cloud layer below an ice cloud layer with a plausible choice of arguments. To get an operational algorithm for determination of cloud parameters from individual layers, additional informations about the spatial evolution of spectral characteristics can be used, which are different for both cloud layers. During the EGS meeting potentials and limits of such a procedure, as well as the profit of additional synergetic information from active instruments shall be discussed.

DETERMINATION OF THE SHORTWAVE ANISOTROPIC FUNCTION FOR CLEAR-SKY DESERT SCENES FROM SCARAB DATA. COMPARISON WITH MODELS ISSUED FROM OTHER SATELLITE DATA

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Determination of directional albedo and bi-directional anisotropic function are necessary to the radiance-to-flux conversion. The most recent model, used for the Earth Radiation Budget Experiment (ERBE) data is based on data from the Sun-synchronous Nimbus-7 mission, observing close to local noon. Because the desert zones are restricted in latitude (20° to 35°, in each hemisphere), only a small range of solar zenith angle was sampled. Here the author considers, for clear-sky desert regions, the improvements that can be made using non-Sun-synchronous satellite data, precessing in local time. This study made from ScaRaB data (Scanner for Radiation Budget, on board the Meteor-3-07 satellite) concerns the clear-sky deserts. The four great deserts on the Earth (Sahara, Arabian Desert, Namib-Kalahari, Australian Desert) have been considered. A normalization method, here explained, makes it possible to combine the values of bi-directionel anisotropic reflectances of all study areas for each desert. Then only one characteristic function is obtained for each desert and it is shown how the characteristic function of Sahara may be extended to the other deserts. This study is concluded with a comparison of the albedo and anisotropic functions obtained from different models.

REMOTE SENSING OF CLOUDS USING A GROUNDBASED MULTI-SENSOR SYSTEM

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In order to investigate cloud related processes a groundbased system combining active and passive remote sensing instruments from different spectral ranges has been set up at the Meteorological Institute in Bonn. The sensor package consists of a Vaisala CT25K laser ceilometer, an Heitronics KT19.85 infrared radiometer, a X-Band Radar and a 4-channel microwave radiometer. Ceilometer and infrared radiometer are mounted as one unit on the institute roof and provide information on cloud base height and temperature. The radar located on the roof of a nearby building was currently modernized and can now be fully controlled by software to perform azimuth (PPI), elevation (RHI) and volume scans with typically 1 rpm. The measured radar reflectivities at 9.375 GHz contain information on the precipitation as well as on cloud properties. The microwave radiometer measures the thermal emission of the atmosphere at 4.9, 10.7, 21 and 35 GHz suited for the detection of integrated water vapor and cloud liquid water. To focus on mesoscale processes the instruments were chosen to have narrow beamwidths (about 1° full width at half maximum) and short sampling times (about 1 s). A sophisticated scanning microwave radiometer with three frequency bands will be added in fall 1998. The sensor package and its extension will be described in detail and first coordinated measurements of clouds will be shown.

VALIDATION OF SEMI-TRANSPARENT CLOUD POLDER PRODUCTS USING LIDAR MEASUREMENTS

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Lidar measurements collected simultaneously with ADEOS overpasses are used to validate POLDER semi-transparent cloud level 2 products: altitude, optical depth, discrimination between liquid and ice clouds. This validation is based on lidar ground-based data collected in 5 different sites.
The lidar measurements allow to retrieve:
- the structural characteristics of scattering layers (ie; cloud altitude and geometrical thickness),
- the backscattered profiles from which semi-transparent cirrus cloud optical depth can be derived,
- the linear depolarization ratio linked to the cloud water phase (ice or liquid).
Preliminary results will be presented.

INVESTIGATIONS OF CLOUD LAYER BASE AND TOP HEIGHTS FROM 95 GHZ RADAR REFLECTIVITY DATA

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Cloud radars operating at millimeter wavelengths have proven to be invaluable for studying the vertical distribution i.e. of stratiform clouds. An improved knowledge of the occurrence of multiple cloud layers as well as of heights of their upper and lower boundaries is of essential importance for the determination of radiative fluxes with a better accuracy. In this study, data obtained from measurements with the 95 GHz radar of GKSS Research Centre, Geesthacht, is used to determine base and top heights of layers of different cloud types. However, an accurate retrieval of cloud boundaries by remote sensors is not trivial, e.g. simultaneous measurements of the radar and backscatter lidars often show significant differences in cloud base heights caused by precipitating particles falling out of the cloud and giving a significant contribution to the radar signal underneath the real cloud. Another feature frequently observed in height-time sections of the radar reflectivity is the signal attenuation by liquid water causing an underestimation of cloud top heights or a partial loss of sections of upper layer clouds in the presence of liquid clouds and especially of rain underneath. Therefore, algorithms which have been developed to correct for the biases in cloud base estimation as well as for the attenuation effects will be described. These correction methods use the Doppler velocities measured by the radar as an indication for the presence of precipitation which is most responsible for both error sources. Applied to long-term datasets, the implementation of these algorithms will ultimately lead to a more reliable statistics of typical cloud boundary heights necessary to improve radiative transfer calculations.

OFF-BEAM LIDAR: AN EMMERGING TECHNIQUE IN CLOUD REMOTE-SENSING

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Traditional (on-beam) atmospheric lidar reveals little about boundary-layer clouds due to their extreme optical density compared to the "clear" atmosphere, including aerosol and even cirrus layers that are readily penetrated by the laser beam. On-beam returns of course enable the detection and ranging of a layer cloud (cielometry from below, cloud-top geometry from an airborne platform); with some effort, information about the water phase can also be inferred. However, lidar photons are not absorbed but scattered out of the beam; most of these escape the cloud through an extended diffuse pattern in reflection that evolves in time. For all practical purposes, this is the cloud's radiative Green function (rGf). We present compelling empirical and numerical evidence that establishes the following rGf properties for typical marine Sc (physical thickness $\Delta_z \approx 300$ m, optical depth $\tau = 10$–40, and "C1" scattering):

- lateral extension in r.m.s. diameter is 0.5–1.0 km, all times considered;
- temporal rGf peaks beyond cloud thickness and has a tail extending beyond 2 km.

Most importantly, rGf theory is analytically tractable within the photon-diffusion and homogeneous-cloud approximations (the latter can be relaxed to some extent). This tells us Δ_z, τ and, possibly, an internal variability parameter can be retrieved from Off-Beam Cloud Lidar returns from stratus decks at a single wavelength. (N.B. mm-radar, also quite new, is the only other viable remote-sensing technique for this task.) We report on laboratory experiments and describe planned field experiments.

MICROSCALE INHOMOGENEITIES STUDY USING HIGH RESOLUTION POLAR NEPHELOMETER MEASUREMENTS

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10 centimeters resolution measurements of the hydrometeor scattering function into an alto-cumulus cloud layer are presented. Comparisons of inhomogeneity properties are made with other microphysical measurements (using FSSP and 2D-C probes) and with visible radiance of AVHRR satellite image. A broad range of spatial scales is thus available to quantify spatial inhomogeneities of this cloud. The Fourier energy spectra, the probability density function of the length of cloud/non-cloud events and the fractal dimensions are estimated inside this spatial range. For these three independent quantifications of inhomogeneities, results indicate a scaling range of cloud distributions between 1 meter and at least 100 kilometers. The Fourier spectra have a power law behaviour with a slope of -1.55 +/- 0.05 significantly larger than the slope of dynamical or passive scalar spectra in a three dimensional turbulent field (-5/3). The probability density functions of cloud gap lengths are characterized by a power law decrease with a characteristic exponent nearly constant with the threshold chosen to define the cloud and clear air regions. The mass fractal dimension also indicates a small sensitivity to the cloud segmentation threshold, yielding to a quasi mono-fractality of this non precipitating cloud layer. Contrarily to a multifractal behaviour, mono-fractality could considerably simplify the parametrisation of inhomogeneities because it reduces the number of pertinent parameters. Comparisons between observations and probabilistic models of cloud layers are discussed using these three quantifications of cloud inhomogeneities.

HETEROGENEITY EFFECT ON MICROPHYSICALS RETRIEVAL PARAMETERS BY SATELLITE AT DIFFERENT SCALE.

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Satellite cloud cover and cloud properties determination, using the Independant Pixel Approximation (Cahalan,1994 et al.;...), are very affected by cloud heterogeneity at different scale and especially at subpixel scale. In the purpose to compare retrieval parameters with radiometers of various pixels sizes we investigate how the area-averaged microphysicals retrieval parameters can be affected by cloud inhomogeneity and what is the effect of the observation size. This study has been achieved for one part using AVHRR data during the SEMAPHORE experiment to obtain spatial expansion between 3 to 10 km. Retrieval optical tickness and effective radius can be express as a function of cloud heterogeneity parameter. In a second part a 3D radiative transfer model, such as Monte Carlo, is used to model inhomogeneous cloud which are generated with different stochastic cloud models to study effects of cloud subpixel fractional cover on retrieval parameters.

VALIDATION OF SATELLITE CLOUD PARAMETER RETRIEVAL METHODS WITH OBJECTIVE GROUND BASED MEASUREMENTS

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To understand and model the radiative transport in a cloudy atmosphere information on the cloud height and optical thickness is indispensable. Therefore retrieval techniques are developed for the AVHRR, ATSR and the future MSG and ERM. For validation objective physical measurements are necassary. At KNMI retrieval methods for cloud parameters from AVHRR and MSG observations are developed. Much effort is put in the difficult but crusial task of validation.The retrieval methods are validated with a two-year data set from the KNMI Cloud Detection System (CDS). The CDS, which combines satellite and ground based instruments, was designed to characterize cloud fields within a 130x130km2 area. The ground network consists of 10 stations for remote sensing. Each station has a lidar ceilometer (height) and an IR-radiometer (temperature). Very detailed analysis is performed with observations from the CLARA-campaigns, when the following advanced instruments were added to the CDS: high power lidar, radar, microwave radiometer and an infrared-video- camera. Microphysical properties were measured from an aircraft. As a result the CLARA-dataset enables the study of synergy algorithms for the ESA Earth Radiation Mission. Some examples of actual measurements can be found on the CLARA-pages: 'http://www.knmi.nl/CLARA' The presentation will show the use of the CDS- and CLARA-observations for validation of satellite cloud parameter retrieval methods.

COMPARISON OF MEASURED AND MODELED OXYGEN A-BAND HIGH RESOLUTION ABSORPTION SPECTRA AS A TEST FOR RT-CALCULATIONS.

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Using high resolution spectroscopy of the atmospheric oxygen A-band rotational absorption lines, the probability density function of geometrical photon pathlengths (PDF-GP) were measured under clear and cloudy sky conditions. A large enhancement of the mean geometrical pathlength and a significant change in the shape of the PDF-GP is found for under cloudy sky conditions. Our observations are consistent with Gamma type distributions. For several cases of cloudiness the measurements are compared with a radiative transfer model in order to validate the treatment of the multiple Mie-scattering in clouds. Our measurements show a significant discrepancy compared to a model (DISORT) assuming plane parallel homogenous cloudiness. In order to understand this discrepancy the statistics of the photon diffusion through clouds as incorporated in the model is investigated in more detail. A Monte Carlo model is used to study the effect of 3D inhomogenities.

GROUND BASED PASSIVE REMOTE SENSING OF ICE CLOUDS WITH SCATTERED SOLAR RADIATION IN THE NEAR INFRARED

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The feasibility of ground based passive remote sensing in the near infrared for the estimation of optical properties of thin ice clouds was examined and confirmed. The radiative transfer through ice clouds was simulated as a function of crystal size, crystal shape and optical depth under the assumption of single scattering. A method is derived to estimate the effective radius for optically thin ice clouds from radiances at 1046 and 1550 nm. The results are not dramatically different if one assumes hexagonal crystals or surface equivalent spheres. The estimation of the ice cloud optical depth depends however strongly on particle shape, leading to a less reliable estimate.

Ground based spectral measurements of scattered near infrared solar radiation have been used to verify and to apply the derivation technique. The evaluation of measure-ments for different ice cloud types and contrails yields mostly particle sizes between 30 and 200 5m. Occasionally they are as small as 1.6 5m or as large as 600 5m. The known increase of particle size with cloud base temperature was confirmed. Contrails prove to contain small crystal sizes that increase with age to the values found in the surrounding cirrus clouds. A systematic size reduction in contrail clouds older than 30 minutes is indicated but cannot be conclusively proven by the present data.

ON THE DEVIATION OF THE BIDIRECTIONAL REFLECTANCE OF INHOMOGENEOUS CLOUDS FROM THE PLANE PARALLEL MODEL

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Clouds are currently treated as homogeneous plane-parallel layers in the derivation of cloud properties from satellite radiances. However, cloud inhomogeneities are known to influence the radiation field anisotropy. Monte Carlo simulations of cloud bidirectional reflectance were performed using two-dimensional (x and y) fractal distributions of the optical thickness. These distributions were generated with a bounded cascade model with appropriate parameters for overcast, broken and scattered clouds. For simplicity, the cloud droplet size distribution is assumed to be constant within the clouds. The cloud optical thickness is related to the square of the geometrical thickness according to the adiabatic approximation. When comparing with plane-parallel cloud simulations, biases on the inferred albedo and the inferred optical thickness vary with the viewing angle. In a lot of cases, they are more than 50% in particular viewing directions. Due to measurement noise and uncertainty on the microphysics that also affect the anisotropy of the radiation field, only morphology effects are expected to be easily detected from multidirectional observations such as those performed from the POLDER radiometer on board the ADEOS platform.

SINGLE-COLUMN MODELS, ARM OBSERVATIONS, AND GCM CLOUD-RADIATION SCHEMES

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Today, the global-climate model (GCM) provides our best look at the climate of the future. However, the simulated future climate will be realistic only if the GCM adequately captures the essential physics of the climate system. Among the most serious sources of uncertainty in GCMs today is the treatment of clouds and cloud-radiation interactions, especially in their regional aspects. Cloud parameterizations need to be tested thoroughly against observations, using both in situ and remote sensing technology. Until recently, we have had far too many parameterizations and far too few observational data with which to test them. Now that situation is improving rapidly. Among the best sources of useful observations is the Atmospheric Radiation Measurement (ARM) program of the U. S. Department of Energy. Other field programs have also made important contributions as well. My collaborators and I have used single-column diagnostic models to make the link between observations and parameterizations, which we then test in GCM experiments. We find that schemes with explicit cloud water budgets and interactive radiative properties are potentially capable of matching observational data closely.

A MULTIDIMENSIONAL HISTOGRAM METHOD TO ANALYZE AVHRR DATA

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Histogram method is based on the idea that a histogram of the pixels in an area will show clusters of pixels that represent cloud or surface types. Assuming that the clusters have normal distribution an initial histogram can be treated as a mixture of normal components. A scheme to separate the components and estimate their parameters (mean, variance and weight in the mixture) in multidimensional case will be presented. The scheme enables one to utilize several auxiliary variables (such as CH2/CH1, CH4-CH5, CH3-CH4 based on the AVHRR measurements) to ease distinguishing clusters of different cloud and surface types. Examples of the separation in case of 3 and 4-dimensional histograms will be presented.

CLOUD DETECTION IN THE UPPER TROPOSPHERE AND LOWER STRATOSPHERE BY CRISTA 1/2

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The CRyogenic IR Spectrometers and Telescopes for the Atmosphere instrument (CRISTA) was flown in November 1994 and August 1997 during the space shuttle missions STS66 and STS85. CRISTA is a limb scanning experiment that measures the thermal emissions (4-71μm) of 18 trace gases with high spatial resolution in three dimensions. During both missions seven global maps were measured. Radiance fields and single spectra show clear indications for deep convection clouds in the tropics (CRISTA 1/2) and polar stratospheric clouds in the southern polar vortex (CRISTA 2). Analyses of the cloud distributions and properties retrieved by the IR-emissions will be discussed. A comparison with the SAGE II climatologie for subvisible cirrus clouds will also be presented.

CIRRUS CLOUD PARTICLE SIZING USING SPACEBORNE RADAR/LIDAR SYSTEM

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Based on the radar/lidar backscatter ratio technique developed by Intrieri et al. (1993) and assuming cirrus ice particle spherical, the EUCREX and CEPEX datasets have been analysed to test the retrieving algorithm of cirrus IWC and particle size for a future spaceborne radar/lidar system. The results show consistent agreement between those observed and those inferred from the spaceborne system. Some retrieving problems will be discussed.

CLOUD SIMULATIONS WITH RANDOMLY ORIENTED AXIALLY SYMMETRIC HYDROMETEORS.

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A code developed by Mishchenko based on T-matrix approach has been modified. Then, in addition to the evaluations of C_{ext}, C_{sca}, C_{abs}, w (albedo), <cos θ> (asymmetry parameter) and the non-zero elements of Mueller matrix at different scattering angles, we can now estimate a set of parameters which are even more useful to radar applications: backscattering cross section, attenuation coefficient, reflectivity Z (expressed in dBZ), IWC and LWC, either for ice or water clouds. For mixed-phased clouds we use a Maxwell-Garnett model to evaluate a statistically equivalent complex refractive index, so they will be treated as well as a single-phased cloud. Hydrometeor's models shapes can be spheroids (prolate/oblate) and Chebyshev particles (even order). We also modified the original code of Barber and Hill, dealing with monodisperse populations, for conical hydrometeors (Wang particles) at different deformation parameters. For the same particles it's possible to calculate all the above mentioned radar parameters. The calculations are made at different frequencies (typically 5.6, 14, 24, 35, 78, 94 and recently 125 GHz). For polydispersions (modified Mishchenko code) it's possible to choose different kinds of size distributions (most used are a modified Gamma and a power law Hansen/Travis). Finally both modified codes allow depolarisation radar parameters (ZDR, LDR, CDR) to be calculated, which give useful informations on shape, composition, and canting angle of the cloud. Backscattering cross sections have been compared with a simplified code developed for validation. Reflectivity and IWC/LWC detections have been compared with semi-empirical laws derived by direct measurements, while depolarisations are compared with Matrosov models.

OUTLINE SPECIFICATIONS OF GROUND-BASED CLOUD RADARS AND THEIR POSSIBLE INVOLVEMENT IN THE EARTH RADIATION MISSION

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In the course of a feasibility study performed for ESA/ESTEC recommendations for the type and outline specifications of ground-based cloud profiling radars have been developed. The selection process was based on the results of a thorough physical description of cloud macro- and microstructures, scattering calculations, components/subsystems availability and cost factors to be expected in case of realisation. Governed by the higher density of the cloud/precipitation environment when looking into it from the ground, 14 GHz was chosen as the preferred frequency, allowing the recognition of high clouds even in precipitation situations. This frequency would also be suited to acquire information on the transition from cloud to precipitation and the microstructure of melting layers. For an optional dual-frequency design 35 GHz was selected as the second frequency, paying attention to an economic realisation. In order to avoid the need for high-power amplifying transmit tubes, the use of pulse compression and/or modulation was not recommended, but rather the application of receiver-coherent Doppler principles for the purposes of velocity and turbulence extraction, achieving the required sensitivity by means of coherent echo integration. Further recommendations were the provision of cross-polar echo reception and a limited antenna beam scanning applying a novel hydraulic dual-plate pedestal. Main application in the frame of the ERM would be to provide spotwise ground truth and validation data for spaceborne cloud sensors.

95-GHZ RADAR/720-NM LIDAR SIMULTANEOUS MEASUREMENTS OF CLOUDS AT GKSS

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Comparisons have been made of the cloud profiles obtained from the backscatter signals of a 95-GHz radar and a 720-nm lidar system between 23 May and 4 November 1997 at Geesthacht (53°24' N, 10°26' E). Time and height resolution were 2 s and 75 m for both devices. Although the wavelengths of the two systems differ by a factor of 4 000, remarkably similar data have been obtained in many cases. There are differences, though. In the presence of an altocumulus at 2.6 km height and a moderately thick stratus around 800 m the lidar senses only the stratus, whereas in the radar profiles the altocumulus shows up nicely and the stratus is barely perceptible. A cirrostratus with cloud bottom around 6 km is seen by both systems. Whereas the lidar beam penetrates no deeper than about 2 km, the radar shows the entire body of the cloud which at times is more than 6 km thick. The downward internal motion of the cloud is detected by both systems, the lower cloud bottom from the radar data is attributed to the presence of raindrops below the cloud. A similar picture is obtained for a thick, multilayered stratus between 0.6 and 2.5 km for which again the lidar senses only the lower parts; a layer of haze at about 400 m is, on the other hand, seen by the lidar only. Finally, moderately thick cirri between 7 and 11 km that strongly show up in the lidar signal are not detected by the radar. In conclusion, both systems provide cloud dynamics data; whereas the lidar is more sensible to thin clouds, the tops of thick clouds are only seen by the radar. Lidar and radar cloud bottoms appear lower if made up of small and large particles, respectively. For quantitative cloud studies collocated radar-lidar systems thus considerably add to the experimental capabilities of each of the two systems alone. Model calculations are under way to quantify the effect of particle size on the return signals.

SCATTERING CALCULATIONS FOR THE SIMULATION OF RADAR RETURNS IN REALISTIC CLOUD SCENARII

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The simulation of radar returns in realistic cloud scenarii is one important step before the actual hardware design of a cloud profiling radar. Scattering calculations were done within the feasibility study for a ground based cloud profiling radar performed under ESA/ESTEC contract. The main purpose was to be able to simulate radar returns and radar parameters for different cloud situations as expected to be measured by a cloud profiling radar. Particle spectra have been modeled by polydisperse distributions of water droplets and spheroidal ice particles with different size / diameter relations. A literature study on the micro- and macro-physical characteristics of four major cloud types (high clouds, middle layer clouds, low clouds and clouds with precipitation) has been performed and sample particle spectra were used for the simulation of radar returns in realistic cloud scenarii. Six frequencies between 5.6 GHz and 94 GHz were investigated. Rayleigh approximation was assumed for the small particles, ice particles with larger size parameter have been calculated using the Fredholm integral method. Needles and plates within these populations have been simulated by spheroids with extreme axial ratios. The radar parameters reflectivity, specific attenuation and linear depolarisation ratio have been calculated from the digitized spectra so that sensitivity calculations and attenuation budgets have been obtained for various cloud types.

OA15

OA15 Clouds and their impact on radiation and photo-chemical processes

Convener: Raschke, E.

02 Modelling of cloud systems

Convener: Mölders, N.

REMO IN FORECAST MODE WITH ICE PHYSICS IN THE CLOUD AND IN THE RADIATION SCHEME

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A main purpose of the REgional scale MOdel REMO, as implemented at GKSS, is the determination of the water and energy budgets over the Baltic Sea and its catchment area within the Baltic Sea experiment BALTEX. REMO (GKSS) is essentially the same code as the regional weather forecast model 'Europa Model' (EM, version 2.11) of the German weather service.

To improve the performance of forecasting the water and energy budgets, the model has been enhanced by a prognostic ice phase variable and the cloud and radiation scheme have been completed with ice physics. Since in REMO the cloud cover is not a prognosed variable, the diagnostic parameterisation also has been revised.

In this paper we present the changes in a few simulated parameters with major relevance for the mentioned budgets: the cloud cover, the liquid and ice water path, and precipitation. Also we compare these simulation results with observations, namely with the DX data set of the ISCCP (International Satellite Cloud Climatology Project) and with measurements from about 6000 rain gauge stations within the Baltic Sea region. The spatiotemporal meteorological fields are contrasted by means of statistical objective analysis.

THE PARAMETERIZATION OF THE MICROPHYSICAL PROCESSES AND THE RADIATIVE TRANSFER IN THE MESOSCALE MODEL MEMO

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The prognostic mesoscale model MEMO simulates the atmospheric wind field which is necessary to calculate the dispersion of pollutants. Microphysical processes, such as condensation and evaporation, and radiative transfer influence the atmospheric energy budget and therefore the atmospheric flow. In this paper a method is presented to include these influences into mesoscale wind flow modelling. Therefore condensation, evaporation and precipitation are parameterized. The parameterization requires a radiation scheme which resolves the radiation transfer in presence of single clouds. The parameterization of longwave radiation is based on an enhanced emissivity method. Shortwave radiation is calculated considering multiple reflexions between single clouds. The emissivities, transmissivities and albedo are dependent on the liquid water content of the cloud and its vertical extension. Both are calculated by the parameterization of the microphysical processes. The scheme is suitable for the use in mesoscale models since droplet spectra are not considered and therefore the computational effort is small. Results from one-dimensional calculations and from real-case applications for parts of the Portuguese coast are presented to show the influence of microphysical processes and radiation transfer on the atmospheric wind field.

SHORTWAVE CLOUD FORCING OF MARINE STRATOCUMULUS CLOUDS

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Clouds are an important modulator of climate, especially marine stratocumulus with their high reflectivity and high emission temperature. These effects combined gives a strong net radiative cooling. It is therefore important to see how the forcing depends on cloud cover, position and water content. The results are based on the radiative code of NCAR CCM2 using a single column model. Marine stratocumulus clouds are chosen because of their near plane-parallel structure and because the ocean has low reflectivity, which provides an excellent background for remote sensing of radiative properties. The model gives the diurnal average cloud forcing with constant cloud cover, effective radius and integrated liquid water content. The effects on the shortwave cloud forcing when altering the cloud's vertical position, cloud cover and water content will be discussed. One finds that the shortwave forcing is nearly insensitive to the cloud's vertical position whereas cloud cover is the crucial parameter for thick clouds, and liquid water path is a more sensitive parameter when the cloud is thin. It is also interesting to see whether the model can reproduce the shortwave forcing measured by satellites given measured water content and cloud fraction. The code overestimates the forcing but this might be explained by a fractal cloud cover, a broken cloud cover, a different effective radius, the diurnal variations in cloud properties or measurement errors. An assessment of the respective effects is presented so one can better relate the results from this model to measurements of shortwave cloud forcing.

DESIGN, TESTS AND FIRST APPLICATIONS OF A TWO-MOMENT WARM CLOUD SCHEME IN A NON-HYDROSTATIC MODEL

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A warm cloud scheme predicting the mixing ratio and number concentration of both the cloud droplets and the raindrops has been incorporated in the multi-purpose non-hydrostatic mesoscale model "MésoNH". The scheme is based upon generalized γ-law distributions for each liquid water specy. Special attention has been paid to describe the nucleation and coalescence processes for which analytical solutions have been considered. The CCN nucleation subscheme is an extension of Twomey's work but includes the finite availability of the CCN source. The accretion and self-collection tendencies have been fully integrated using the Long polynomial kernels while the autoconversion rate is accounted through the Berry and Reinhardt parameterization. Each microphysical process has been run separately in 0D numerical experiments in order to estimate the accuracy of their representation in the complete scheme.
Finally, we present 2D numerical experiments using the whole warm cloud parameterization for some selected case studies of orographic and other precipitating clouds. The sensitivity of the results to the initial activation spectrum is discussed.

IMPACT OF A NEW PARAMETERIZATION SCHEME FOR NON-SPHERICAL ICE CRYSTALS ON THE CLIMATES OF TWO GCMS

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Until recently ice clouds have been treated crudely in general circulation models (GCMs) of the atmosphere. Many models made no distinction between water and ice clouds, and those that did considered ice crystals as spheres of a given fixed size. In nature ice spheres are rarely found. The non-sphericity of real ice crystals strongly affects their radiative properties, both in SW and in LW, and those two effects do not cancel. Furthermore, ample observational evidence exists for a strong temperature dependency of ice crystal sizes. A new parameterization scheme suitable for GCM applications that takes the above properties of ice crystals into account has been developed and implemented in the UKMO and NCAR GCMs. We shall present results from 5-year simulations with both models, indicating the impact on model climate. In many respects the two models respond similarly to the changes in ice crystal treatment. For instance, both models show a warming of the tropical tropopause of about 1 K, reduces a persistent bias in the models. This is shown to be largely related to enhanced LW radiative warming. Other features of the model results will also be presented, along with investigations of potential impact on cloud feedback.

A RADAR SIMULATION MODEL FOR THE VALIDATION OF MESOSCALE DYNAMIC MODELS

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A radar simulation model has been developed in order to validate the three-dimensional fields of precipitation and cloud water/ice calculated by the non-hydrostatic Lokal-Modell (LM) of the German Weather Service (DWD). In our simulations we focus on an area of about 400x400 km² around the C-band radar located in Essen (51.4°N, 7.0°S), which is a part of the DWD radar network.
The radar propagation model considers the curvature of the radar beam relative to the earth's surface depending on the temporal and spatial variability of the refraction index in the troposphere. The complete atmospheric interactions of an electromagnetic wave, i.e. backscattering and attenuation, are included. Gaseous molecular absorption (oxygen and water vapour) is calculated using the model by Liebe (1993). The extinction and backscattering cross sections of the four types of hydrometeors (rain, snow/hail, cumulus clouds, cirrus clouds) are calculated following Mie theory based on typical particle size distributions. From the total cross section the radar reflectivity is derived.
Several sensitivity studies for stratiform and convective precipitation events will be shown by comparing simulated plan position and range height indicator images of different radars based on LM runs with observations of the DWD radar network at the same time.

EXPERIMENTALLY DETERMINED PHOTON PATHLENGTH DISTRIBUTIONS FOR DIFFERENT METEOROLOGICAL SITUATIONS

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Experimentally determined probability density functions of geometrical paths (PDF-GP) for different meteorological situations are presented. The PDF-GPs are deduced from high resolution spectroscopy of zenith-scattered sunlight within the oxygen A-band. The method that allows to derive the PDF-GP involves the determination of differential optical densities of several A-band absorption lines applying the DOAS (Differential Optical Absorption Spectroscopy) technique, and a Laplacian back-transformation. The results presented show large enhancements of the first moment of the pathlenth distribution function, when cold and warm fronts pass over the measuring site (50°N, 8.2 °E). Furthermore, the results exhibit significant temporal variations of the PDF-GP for rapidly changing weather conditions and they clearly show that multiple Mie-scattering within clouds does have an important impact on photon paths and their length-distributions.

DIURNAL VARIATIONS IN STRATOCUMULUS-CAPPED ATMOSPHERIC BOUNDARY LAYER

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A model simulation is presented of the diurnal cycle of a cloud-topped atmospheric boundary-layer (ABL). A turbulent-radiative description is developed based on a two-stream radiative scheme and a one-and-half order closure. In order to examine model performances, nocturnal model results are compared with ASTEX datasets obtained during the night of 12-13 June 1992. Different turbulence closures are tested using a one-dimensional (1D) version of a 3D vorticity-mode mesoscale model (TVM). The TVM model uses prognostic equations for liquid potential temperature $\overline{\theta_l}$ and total specific humidity $\overline{q_t}$. The buoyancy term as well as other turbulent fluxes of the non-conservative variables are expressed as a function of a saturated and unsaturated fluxes of $\overline{\theta_l}$ and $\overline{q_t}$ which are combined through a weighting factor that represents the fraction of saturated air. The different closures give satisfactory mean meteorological fields. However, a wider scatter is exhibited by turbulent fields. The model is used to study the impact of different combinations of physical processes on the turbulent structure of a cloudy ABL. The physical processes considered are i) surface heating flux, ii) infrared cooling near cloud top, and iii) solar radiation in the cloud. The simulations show a diurnal variation in cloud properties, as a result of the absorption of solar radiation within cloud layer.

Different cloud prediction by use of various types of cloud models included in one mesoscale model

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The non-hydrostatic mesoscale meteorological model GESIMA (GKSS Geesthacht) includes four various types of cloud models. All these models are able to predict clouds or various components of clouds.
The cloud models are used to calculate the thermodynamic processes within an Sea Breeze situation at the Baltic Sea coast and during the existence of so called Baltic Heat Cyclone.
In the first case the predicted time dependent rain and in the second case the time and spatial distribution of snow are used to demonstrate the discrepancies between the various cloud schemes.
These discrepancies show, that without any tuning of parameterization of microphysical processes and of the boundaries between the defined components of clouds it is nearly impossible to compare the predicted cloud cover, rain or snow.

ON THE SENSITIVITY OF CLOUD MICROPHYSICS TO THE ENERGY AND WATER FLUXES AT THE INTERFACE EARTH-ATMOSPHERE

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The sensitivity of the cloud and precipitation formation processes on the choice of the soil-vegetation-atmosphere-transfer-scheme (SVATS) to predict the water and energy fluxes at the interface Earth-atmosphere is examined by using alternatively two different SVATS in a non-hydrostatic meteorological model. The first SVATS is a Deardorff-type scheme using a force-restore-method for the soil moisture. Herein, soil moisture and soil temperature are decoupled (cf. Eppel et al. 1995). The second SVATS, however, considers the dependence of soil temperature on soil moisture and vice versa (cf. Kramm 1987). The cloud module applied is a five water class bulk-parameterization scheme.

Due to the differences in surface temperature and moisture supply to the atmosphere and due to the resulting differences in stability appreciable differences in the cloud microphysics and the paths of precipitation formation may occur. First results of the comparison will be presented and discussed. Such studies will be important to quantify the uncertainty in studies on the local recycling of water.

NUMERICAL INVESTIGATIONS OF PRECIPITATION FORMATION IN WARM CONVECTIVE CLOUD.

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Characteristic features of the process of precipitation formation in a warm cloud was investigated with the help of one-dimensional, time-dependent cloud model. Microphysical processes of nucleation, condensation and coalescence were modelled in detail by means of numerical solution of stochastic collection equation For the processes of condensation and coalescence original numerical schemes were elaborated, capable to conserve the mass and the number of particles and at the same time obtaining accurate solutions for the relatively low number of drop size intervals.
Considerable efforts were made to investigate the dependence of the processes of precipitation formation upon environmental atmospheric conditions (temperature lapse rate, humidity vertical distribution and surface temperature) and on the rate of cloud microphysical processes defined by number of nucleation nuclei and collection efficiency.

ON THE INFLUENCE OF THE CLOUD MORPHOLOGY AND INHOMOGENITIES ON OPTICAL PATHLENGTHS AND THE CLOUD SKY SW-ABSORPTION

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Recently several studies have highlighted the existing uncertainty in the observed and modeled cloudy sky absorption of the solar radiation (SW-absorption). Thereby it has been suggested that the frequently made assumption in radiative transfer calculations (RT) to represent clouds as homogeneous plane-parallel instead of fractal (broken and inhomogeneous) entities could be a possible cause for this uncertainty. More specifically spoken it was argued whether such simplified RT-calculations can accurately model the probability density distribution of optical pathlengths (PDF-OP) of real clouds, and in consequence may fail to calculated accurately the cloud sky SW-absorption. The present talk addresses this problem by reporting on the first cloud sky PDF-OP measurements using the oxygen A-band technique. These measurements are compared with RT-calculations of the cloud sky PDF-OPs using the DISORT-code. From the discrepancies found between the measured and modeled PDF-OPs it is concluded that non-statistical RT-models indeed fail to account properly for the intermittency of the optical pathlengths occurring under cloudy sky. Consequences of this model shortcoming on calculated cloud sky SW-absorptions are also discussed.

OA15 Clouds and their impact on radiation and photo-chemical processes

Convener: Raschke, E.

03 Radiative transfer and budget

Convener: Ohmura, A.

CIRRUS CLOUD OPTICAL PROPERTIES IN THE FAR-INFRARED

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The contribution of cirrus clouds to the Earth-Radiation Budget (ERB) is very important in improving Global Circulation Models which are the basis for estimating long-term climate change. Cirrus clouds, composed of ice particles, act to reflect the incoming solar radiation emitted from the earth and to reduce the infrared energy radiation loss from the earth. The final effect can be both an atmospheric warming or cooling being the far infrared portion of the long-wave spectrum very important in the resulting balance. In the spherical particles approximation, Mie and Radiative Transfer Theories provide analytical calculation of cloud optical properties wavelength by wavelength. The computational time request for this procedure is very often too big for many applications (e.g. forecasting, Small-Scale Models...). A new parameterization of cloud optical properties has been carried out in order to by-pass some limitations of parameterization found in the literature in the far infrared spectral range. We have modelled the cloud emissivity as function of the Ice Water Path (IWP), cloud thickness, angle of observation and effective particles size parameters (R_{eff}, υ_{eff}) between 10 and 200 μm. The forward and scattered transmissivity and the scattered reflectivity are all included in the emissivity expression. The results have been compared with the ones calculated by other authors and with the analytical Mie Theory resolution. The mathematical process and the final analytical expressions for all the terms considered in the emissivity calculation are reported. The parameterization developed has been implemented in a two-stream approximation radiative transfer code Climcode developed by J. Edwards. Finally, the TOA upward flux variations as function of the cirrus clouds optical and physical parameters are discussed.

HEATING RATES IN FIVE ATMOSPHERIC LAYERS FOR SELECTED CLOUD CASES IN EUROPE

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For selected cases between 1990 and 1996 radiation budget components at top of atmosphere, at different atmospheric levels and at surface were inferred from NOAA-AVHRR and Meteosat data. The investigated area is limited to Central Europe and to the Baltic Sea.
To calculate the radiation budget components at different atmospheric levels and at surface from remotely sensed data, a complex analysis scheme could be applied, where cloud types as well as their optical properties could also be derived. To define the vertical profiles, synoptical observations as well as the cloud classification results were taken into account. Thus for different cloud cases, like deep convective or shallow convective clouds or thin high clouds above thick low clouds, heating rates were computed for only five thick atmospheric layers. But significant differences between heating / cooling in the five layers for these cloud cases can be shown. Analysing the high temporal resolved Meteosat data, the time evolution of heating / cooling in these five layers could also be determined.

FAR-INFRARED SCATTERING EFFECTS IN CLOUDY SKY

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Correct cloud parameterization is crucial for improve accuracy of climate models and for meeting the goals of the Earth Observing System (EOS).The far infrared properties of clouds are still not well-known although the contribution to the radiative forcing in this spectral region is expected to be relevant. In the long-wave it is usually assumed that the effect of absorption is dominant compared with those of scattering. We have investigated the effects of scattering processes using a two-stream approximations radiative code with a new far-infrared parameterization of cloud scattering processes. Results shows that scattering generally increases the optical depth of the cloud and reduces the OLR, and the most relevant effects on cloud top cooling and cloud base warming. Scattering processes can be parameterized as function of ice water path and of cloud effective particle size distribution parameters The maximum effect of scattering is to change the outgoing long-wave radiation by several Wm^{-2} equivalent to about few percentage of the total. A surprising result was that the scattering effect is most important in the partial window around 400 cm^{-1}, rather than in the main window region around 1000 cm^{-1}. We explained this result in terms of the wide wavelength dependence of single scattering properties of ice particles near 400 cm^{-1} (such as back-scattering coefficient and single scattering albedo). The same has not be found for water droplets. This region of the spectrum may therefore hold some promise for future remote sensing of particle size in high clouds.

VALIDATION OF DROPLET SPECTRA AND LIQUID WATER CONTENT MEASUREMENTS

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Measurements of cloud microphysics are of crucial importance for studies of the onset of precipitation and cloud radiatives properties. Various instruments are presently available for airborne measurements in clouds: optical spectrometers, optical scatterometers and hot wires. Data from the SCMS experiment held in Florida during summer 1995 provide a unique data set for evaluation of the probes performances. Measurements of the droplet size distribution performed with standard FSSP probes and the Fast-FSSP will be compared and the probe responses will be evaluated as functions of droplet concentration and sizes. The liquid water content derived from integration of these spectral measurements will then be compared to direct measurements with optical scatterometers and a hot wire. This analysis shows that significant discrepancies exist between the probes. They can be significantly reduced by the application of rigorous correction methods which will be presented.

RADIATION BUDGET FOR BALTEX

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The objective of the Global Energy and Water cycle Experiment (GEWEX) is to make available reliable tools for analyzing and predicting the complete energy and water cycle of our climate system on both, global and regional scales. For regional scales, this work is done within five GEWEX continental scale experiments of which one is the Baltic Sea Experiment (BALTEX). For these, special regional models are being applied, which have to be validated against available surface and satellite measurements. For this we use data of the well calibrated Scanner for Radiation Budget (ScaRaB) experiment to compare regional satellite estimates of the top of the atmosphere (TOA) earth radiation budget (ERB) over the BALTEX area against that calculated by the Regional Scale Model (REMO). The ScaRaB experiment, is a successor of the American Earth Radiation Budget Experiment (ERBE) and is designed to measure the short-wave and long-wave components of the ERB within a very high accuracy on scales of about 250km². These data are used to derive regional ERB products on a scale of 18km². Since the variability in the TOA ERB is mostly determined by the interaction of clouds with radiation, such a comparison between satellite measurements and model results gives inside into how reliable a regional model can describe the development of clouds.
We intend to present first results of a comparison of the radiation budget at TOA with a regional scale model for the month March 1994 for the BALTEX area.

Assessment of Poland overall claudiness as the reason for the forecasting of possible climate changes

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According to PCM advices, assessment of cloudiness in Poland has been done by using the results of the latest overground researches related to this element. Diagnosis of cloudiness range is basic for the elaboration of climate changes forecasting in future. Characteristic of claudiness range has been done with using datas: monthly average, seasonal and yearly in a 10-degree scale. The datas were calculated on the base of datas coming from 8 terms for each 24-hours, for 55 synoptic stations from the period 1966-1990. Range of overall cloudiness is characterized by: quantile of a designed range (p=10, 25, 50, 75, 90), number of days with designed mean 24-hours datas which occurr in designed time periods. The numbers of days in accepted classification according to Mr. Okołowicz (fair days, moderately fair days, cloudy days, very cloudy days) show a clearly seen variability during a year period. For obtaining the complex assessment of cloudiness range, the autors at present take into account also the height of occurring clouds. The researches are continuing now.

MONTE CARLO RADIATIVE TRANSFER CALCULATIONS FOR INHOMOGENEOUS MIXED PHASE CLOUDS

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The consideration of cloud radiative properties in cloud remote sensing and atmospheric circulation models is generally based on the assumptions of plane-parallel and homogeneous cloud geometries and constant cloud microphysical properties. The present paper tries to quantify the differences in solar radiative fluxes (albedo, transmission, and absorption) between these idealised clouds and more realistic inhomogeneous and/or broken mixed phase cloud fields. Furthermore, the uncertainties in these fluxes due to the natural variability of cloud macro- and microphysical properties are examined. A Monte Carlo radiative transfer model has been developed and applied to spatially inhomogeneous cloud fields from a mesoscale atmospheric circulation model (GESIMA) and from radar observations (GKSS 94 GHz cloud radar). Cloud microphysics include spherical water droplets as well as non-spherical ice particles with varying degrees of irregularity. The single scattering properties for the non-spherical hydrometeors have been calculated within the geometric optics approximation. The Monte Carlo calculations for solar broad band albedo show that with increasing liquid/ice water content the albedo bias (reduced reflectivity caused by cloud inhomogeinity) increases up to 50 %. However, uncertainties in the ratio of liquid to ice water path have a comparable influence on the albedo and appear to be the major problem in modelling solar cloud radiative properties.

SOLAR RADIATION CLIMATE IN SWEDEN

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Since 1983 a network of 12 solar radiation stations, measuring global radiation, G (Kipp & Zonen CM10/CM11 pyranometers), and direct solar irradiance, I (Eppley NIP pyrheliometers), is operated by SMHI in Sweden. All stations are within the BALTEX area. During the years 1983 - 1996, for which a homogeneous radiation database has been built up, some clear features in the radiation climate show up. The largest difference in G is between the stations Visby (57.67°N, 18.35°E) and Kiruna (67.83°N, 20.43°E). The mean yearly total of G in Kiruna (2804 MJm^{-2}) is 25 % less than in Visby (3742 MJm^{-2}). This is due to both latitudinal effects and differing cloud conditions. The effect of different cloudiness is clearly seen when comparing the stations Växjö (56.96°N, 14.74°E) and Visby. On the average, G is 12 % less at the cloudier site in Växjö than in Visby. At all sites there is a large year to year variation. The difference between the lowest and highest yearly values at each station is 15 %, or more. There is an increasing trend in both G, I and duration of sunshine at all stations. On the contrary, when also considering older measurements from the 60's and 70's, however not homogenised, the trends are weakly decreasing.
Taking the atmospheric water vapour content into account, the Ångström turbidity coefficient, β, could be estimated from measurements of I. Mean values of β during 1983 - 1996 are 0.077 in Lund (55.72°N, 13.22°E) and 0.055 in Kiruna. These values are strongly affected, approximately to the same amount, by the major volcanic eruptions of El Chichon and Mt Pinatubo.

OPTICAL AND GEOMETRICAL PROPERTIES OF NORTHERN MIDLATITUDE CIRRUS CLOUDS OBSERVED WITH A UV RAMAN LIDAR

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Measurements of cirrus optical and geometrical properties are presented. Data have been taken at Geesthacht (53.5 °N, 10.5 °E) in Northern Germany between May 1994 and March 1996. The instrument used for this purpose is a two-laser Raman DIAL for simultaneous measurements of ozone, water vapor and clouds. The wavelengths of the transmitted radiation are 308 and 355 nm. From the elastic return signals at 355 nm detected in both polarization planes and from the corresponding nitrogen Raman backscatter signal at 387 nm independent height profiles of the cirrus-particle backscatter coefficient, extinction coefficient, lidar ratio, and depolarization ratio are calculated. This combination of the Raman lidar technique and the polarization lidar technique yields the most complete set of cirrus cloud parameters measured remotely so far. The cloud mean extinction, lidar ratio and depolarization ratio are given as a function of mid-cloud temperature. A statistical analysis of cirrus top height, top-height and mid-cloud temperature, temperature gradient, and of geometrical and optical depth is presented and discussed. For the first time the dependence of the lidar ratio upon the depolarization ratio is investigated. The material presented is considered as an important data basis for the modeling of relations between cirrus clouds and climate.

THE HETEROGENEITY OF CLOUDS AND THEIR INFLUENCE ON THEIR RADIATIVE PROPERTIES

OA15

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Radiative flux through clouds and cloud fields are very affected by heterogeneity in microphysical and morphological characteristics of clouds. The idea that radiative properties such as optical depth and single scattering albedo of heterogeneous clouds can be dealt as equivalent radiative properties of plane parallel homogeneous clouds at some horizontal scale of averaging seems to be supported both theoretically and experimentally by some recent works (Cahalan et al.,1994; Borde et al.,1996). The present study aims to show how these effective radiative properties can be influenced by the cloud heterogeneity and at what horizontal scale of averaging a heterogeneous cloud can be treated in the framework of plane parallel homogeneous cloud. This minimal horizontal scale of averaging is found to vary considerably with the incidence angle of radiation. Empirical relations have been established to express these effective radiative properties as a function of the mean optical depth and single scattering albedo as well as a cloud heterogeneity parameter. Finally, we compare the results of the present study, based on the definition of an equivalent plane parallel homogeneous cloud, with those obtained from the Independent Pixel Approximation.

THE ANOMALOUS ABSORPTION PHENOMENON OF HETEROGENEOUS CLOUDS

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Since recent publication of Cess et al. (1995), there is a renewed interest in the anomalous absorption phenomenon. Experimental analyses have shown the absorption within a natural cloud becomes more important than that estimated for its equivalent plane parallel homogeneous cloud. Stephen et Tsay (1990) suggested this anomalous absorption phenomenon might be explained probably by taking into account the horizontal heterogeneity of cloud characteristics in the radiative transfer equations. It has been shown previously a heterogeneous clouds can be treated approximately as a plane parallel homogeneous clouds by introducing an effective optical depth (Borde, 1996; Cahalan, 1994).
In the present study, we show a heterogeneous absorbing cloud cannot be treated as an equivalent plane parallel homogeneous cloud by defining only an effective optical depth, but we also need to define an effective single scattering albedo in addition to an effective optical depth. This means the apparent anomalous absorption occurs in dealing a heterogeneous cloud under the plane parallel cloud assumption, if this apparent effect of the cloud heterogeneity on the single scattering albedo is not taken into account. For a heterogeneous cloud generated with a bounded cascade model, this anomalous absorption may attain a value of 10 to 30 % according the way in which the effective optical depth is estimated; this may reach more than 50 %, when a broken cloud field is considered.

THE ROLE OF THE CLOUD-FREE ATMOSPHERE IN THE PROBLEM OF UNDERESTIMATED ABSORPTION OF SOLAR RADIATION IN GCM ATMOSPHERES

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Large uncertainties exist in the distribution of solar radiation in the global climate system and it's representation in General Circulation Models (GCMs). Based on a comprehensive set of more than 700 surface stations with long term radiation measurements it is shown that GCM atmospheres are typically too little absorbtive and thus too transparent for solar radiation, in the range of 10 - 30 Wm^{-2}. While several studies have pointed to a possible underestimation of solar absorption in clouds which may explain this bias, this study presents evidence that the absorption in the cloud-free atmosphere is too small. These findings are based on a direct comparison of the GCM fluxes with observed clear-sky climatologies derived from composites of cloud-free episodes at surface radiation sites, and on offline validations of the GCM radiation schemes for clear-sky conditions. Quantitatively, the absorption in the cloud-free GCM atmosphere is estimated to be too small on the order of 10 Wm^{-2}, and more in GCMs neglecting aerosols. Possible causes are an underestimation of solar absorption by water vapour and the neglection of aerosol effects.

OA15 Clouds and their impact on radiation and photo-chemical processes

Convener: Raschke, E.

04 Photo-chemical processes in clouds

Convener: Flossmann, A.I.

MODEL OF BIOMASS BURNING PLUME AGEING.

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Biomass burning is influencing atmospheric chemistry by emitting large amounts of reactive species such as: hydrocarbons, organic acids or nitrogen compounds. Polar ice cores provide a unique record of precipitation whose chemistry reflects the atmospheric composition at the time of deposition. Measurements of light carboxylic acids were performed along the Summit ice core (central Greenland) providing simultaneous concentrations peaks for the following species: NH_4^+ (ammonium), $HCOO^-$ (formate), CH_3COO^- (acetate), $C_2H_3O_3^-$ (glycolate), $C_2O_4^{-}$ (oxalate). They were attributed to biomass burning events. A comparaison between the composition of boreal young fire plumes and Greenland ice core concentrations indicates a characteristic in-plume chemistry evolution during the transport. The main goal of this study is to explain the evolution of the 'formic acid / acetic acid' ratio during the plume transport, and the presence of ammonium and formate in stoechiometric amounts in Greenland ice. A box model of gas phase and aqueous chemistry has been used. The chemical mecanisms taken into account are: (1) the gas phase chemistry during the transport time from Canada to Greenland on a typical time scale of 5 days, (2) the influence of the liquid phase, (3) the influence of soluble aerosols on the pH.

Sulfur (IV) to Sulfur (VI) Dark Conversion Mechanisms: A Modelling Study

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Chemical reactions in the cloud and fog droplets have been subject of studies during the last five decades. It is suggested that clouds can convert between 50 to 80% of SO_2 to H_2SO_4 in the troposphere and hence contribute substantially to the formation of the acid rain. Two oxidation pathways, reactions with O_3 and H_2O_2, have been suggested to play important roles. During dark conditions (winter time) too little H_2O_2 is formed by traditional mechanisms, here we will attention to the possibility that ozonolysis of organic compounds may provide a sufficient sum of H_2O_2 to oxidize S (IV) to S (VI) under 'dark' conditions. This study is performed using a box-model (MOCCA) in which quasi-detailed homogenous and heterogeneous reactions of interests were incorporated. We will discuss our results on the impact of various mechanisms on the conversion of S (IV) to S (VI) in the clouds.

Study of the indirect effect of aerosol particles during repeated cloud cycles

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An air parcel model coupled with a detailed cloud microphysical model, was used to study some interactions between aerosol particles and different cloud types during subsequent cloud cycles. Using the inferred cloud microphysical properties together with a Mie calculation code, the cloud optical properties were then estimated. These properties have, in turn, been introduced into a radiative transfer model which calculated the cloud radiative properties such as cloud top albedo and cloud optical depth. The comparisons between the model results and the observations showed a good agreement. Therefore, the model has been used to study the indirect effect of aerosol particles on solar radiation during repeated cloud cycles. Further comparisons between the model results and those of different parameterization schemes, which are presently used in GCM and climate models, showed some of their limitations.

EFFECTS OF CLOUDS ON OH PRODUCTION IN MULTIPLE CLOUD LAYERS AND BROKEN CLOUDS

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The production of OH radicals plays a key-role for tropospheric chemistry. The main source of OH depends on the available UV radiation in the troposphere so that flux enhancement due to multiple scattering is most pronounced when clouds are present. Various cloud configurations are chosen to investigate their role for tropospheric chemistry. The results obtained suggest that cloud top height and vertical cloud arrangement have a large impact on the OH distribution. For finite cloud elements and broken cloud fields locally strong deviations occur as compared to plane-parallel computations. However, when domain averaging is employed the strongest deviations are partly smoothed out so that the independent pixel approach appears to be suitable for photochemical calculations in large-scale models.

LABORATORY AND MODELLING STUDIES OF TROPOSPHERIC MULTIPHASE CONVERSIONS INVOLVING SOME C_1 AND C_2 PEROXYL RADICALS

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The role of organic peroxyl radicals in the atmospheric aqueous phase is currently unclear. Model calculations of the methane oxidation reveal large differences of the obtained concentrations of important gas phase species when phase transfer or liquid phase chemistry is involved in the models. Peroxyl radicals are precursors of peroxides, which play an important role in the tropospheric aqueous phase oxidation of SO_2 to H_2SO_4. The investigations of the reactivity against important cloud droplet constitutents like NO_2^-, Fe(II) and S(IV) and the determination of the T-dependent rate constants for the self-reaction of organic peroxyl radicals are presented in this study. Contributions of peroxyl radical reactions to the overall chemical conversions in different tropospheric aqueous phase compartments will be assessed by means of the recently developed chemical aqueous phase radical mechanism (CAPRAM). In this box model the established gas phase RADM2 mechanism in combined with an extended set of aqueous phase chemical reactions to a multiphase mechanism. The effects of aqueous phase cloud and aerosol chemistry on tropospheric chemistry key species such as C_1 and C_2 peroxyl radicals will be discussed.

A MODEL DESCRIBING TRACE METALS ACTING AS CATALYST IN A MARINE CLOUD.

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Dissolved trace metals, especially d-block, can change their RedOx state and then exchange electrons with other soluble species. Catalytic cycles appear involving a reducing, an oxidant, their associated oxidant and reducing and the involved metal at two oxidation states. Photons may also replace a reducing/oxidant couple. Compared to a more simple reaction scheme without metals, the catalysed reaction system looks much more complex and increases often by a factor 3 the number of reactions to consider. But, while the reaction speed of several branches of the scheme increases considerably, this catalysed reaction system can be turn more simple. We present here a model for remote clouds based on measured concentrations of trace metals in rain water. Copper, iron and manganese are the most active metals.

ACTINIC FLUX COMPUTATION FOR FINITE AND BROKEN CLOUDS IN ABSORBING AND SCATTERING ATMOSPHERES

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From recent ground-based and airborne measurements of the actinic flux in cloudy atmospheres it can be concluded that the horizontal transport of photons must be accounted for in radiative transfer modelling. A small set of five spectral radiative transfer computations within the photochemically active range (290 to 700 nm) is employed. Rayleigh scattering, absorption by ozone and Mie scattering due to cloud droplets are included in two different radiative transfer models: a versatile Monte Carlo code and the so-called Spherical Harmonics Discrete Ordinate Method. The results of both models are in full agreement and underline that 3-D effects in photochemistry cannot be ignored in finite clouds and broken cloud fields. Moreover, both Rayleigh scattering and ground reflection were shown to exert a strong influence on the spatial distribution of the actinic flux.

NUMERICAL STUDY OF CHEMICAL SPECIES EVOLUTION IN A CONVECTIVE CLOUD.

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One-dimensional, time-dependent cloud model for the detailed simulation of interaction between clouds, atmospheric chemical species and radiative fluxes is described. Microphysical processes are modeled in detail by the solution of the stochastic coalescence equation. The gaseous chemistry code includes gas phase reactions for oxygen, nitrogen, hydrogen, chlorine, sulfur species, and detailed methane and ethane chemistry. The aqueous phase takes into account the gas uptake on the surface of cloud droplets and the aqueous phase chemistry. Redistribution of species due to microphysical processes is considered also. The photolysis rates are calculated in the radiation transfer module, based on Delta-Eddington scheme. The main effect of the convective cloud on the chemical composition of the air is the depletion of the well dissolved species concentrations after their removal by precipitation. The radiative processes influence strongly the short-lived species. Coagulation is very important for the transformation of aqueous species in different size droplets and has to be coupled with chemical processes. The vertical transport in a convective cloud is essential for slowly dissolved gases.

OA16 Interaction of biogenic and anthropogenic compounds in the Mediterranean and its influence on atmospheric chemistry

Convener: Seufert, G.
Co-Convener: Hewitt, N.

FIELD OBSERVATION AND MODELLING OF THE FORMATION OF BIOGENIC ORGANIC AEROSOLS IN MEDITERRANEAN AREAS.

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The AEROBIC (AERosol formation from Biogenic Carbon, EC funded project) 1996 experiment was performed to elucidate the mechanisms of organic aerosols formation, through a detailed field study of the chemistry of biogenic hydrocarbons and of the aerosol composition, and an appropriate modelling of the gas phase reactions leading to condensable products. The first experiment took place in August 1996 in a Eucalyptus forest of Portugal. An overview of the main results concerning the "in situ" measurements of gases of photochemical interest (NMHC's, isoprene, terpenes, nitrogen oxides, ozone, carbon monoxide, ketones, aldehydes), aerosol mass and size distributions, total organic carbon in aerosols, and speciation of this organic fraction is given. To analyse these data a 1D model has been used. It includes gas phase chemistry of biogenic hydrocarbons, gas to particle conversion and deposition processes, and uses the latest kinetic data (BIOVOC, EC funded project). The gas to particle conversion of the condensible products of hydrocarbon oxidation is taken into account to calculate i) the evolution of the organic aerosol mass that is compared to observations, ii) the aerosol yield related to the individual hydrocarbons. The changes in CO and O3 budgets due to secondary organic aerosol formation via removal of gas phase reactive carbon from the atmosphere are also discussed.

THE ORGANIC COMPOSITION OF AIR PARTICULATE MATTER FROM SEMI-RURAL AND FOREST PORTUGUESE AREAS

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Particulate matter was collected with high volume samplers during an intensive campaign on August of 1996 in an *Eucalyptus* forest 70 Km far from the coast and two semi-rural areas. The first semi-rural site was located near the sea in the University of Aveiro campus and the second 35 Km distant to the interior in Anadia. Black and organic carbon measurements were performed by a thermal/optical analyser and the aerosols organic extractable matter was characterised by GC/MS. It is noted that atmospheric dispersion and dry deposition over the forest are probable factors affecting the production of total suspended matter, since concentrations at Tabua are lower than at Anadia and Aveiro. Most of the compounds mass identified consists of polycyclic aromatic hydrocarbons with anthropogenic origin, alkanes from vehicular and biological sources, alcohols, ketones and aldehydes from photochemical transformations and other sources, fatty acids with plant and microbial origin and terpenoids from biogenic sources. The distributions of *n*-alkanes show the predominance of C_{29}, which is characteristic of vascular plant inputs. The *n*-alkanols and *n*-alkanoic acids pattern present C_{max} at C_{26} and C_{28}. Important photochemical products like pinonic acid and nopinone were identified having the maximum levels during day and the minimum during night.

ASSESSMENT OF PRIMARY AND SECONDARY BIOGENIC COMPOUNDS IN EMISSION FLUXES FROM AN ORANGE FIELD NEAR BURRIANA, SPAIN

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In the frame of a mesoscalic experiment performed in June 1997 as part of the BEMA project, (Biogenic emissions in the Mediterranean), we measured fluxes of volatile organic compounds above and within a Citrus orchard by means of the TREA (trap enrichment relaxed eddy accumulation) in comparison with the enclosure method. During this period in early summer, when almost no flowers and fruit were present on the trees, emissions observed in zero air enclosures consisted mostly of limonene from the soil and of β-caryophyllene from the leaves. In addition, a couple of other terpenoids were emitted from both sources. TREA fluxes observed directly above the soil were consistent with enclosure measurements and confirmed limonene as the dominant compound emitted from soil covered with leaf and fruit litter. In contrast, highly reactive compounds like β-caryophyllene emitted from foliage could not be observed in above canopy fluxes, in accordance with their fast chemical transformation observed in laboratory studies. Upward fluxes of volatile carbonyls could explain some of the missing carbon, but exact separation of biogenic and anthropogenic origins of carbonyls as the most abundant VOC in ambient air needs further clarification.

SEASONAL CHANGES IN AVOCS- BVOCS AND VOLATILE CARBONYL AIR CONCENTRATIONS IN THE CASTELLON PLAIN DURING 1997.

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The complexity of air mass dynamics in the Mediterranean has already been documented in several EU research projects conducted in the area since 1989 (MECAPIP,REACAPMA, SECAP). It is now clear that the recirculation processes involved, in which new emissions (NOx and other precursors) are incorporated, strongly influence the daily and spatial ozone patterns in the Mediterranean. In this sense the BEMA project's main goal is to study the contribution of different types of emissions, but especially the biogenic ones, to tropospheric ozone formation. It is important to notice that due to Mediterranean climatic conditions strong seasonality is developed, thus the study of seasonal changes in biogenic emissions is expected. For this reason, and as a complementary exercise to the BEMA spring and summer campaigns in Castellon, the air concentrations of VOCs and volatile carbonyls were analysed weekly during 1997at three BEMA sites in the Castellón Plain at different distances from the seashore (5Km, 20 Km and 40 Km). Results show that carbonyls are more abundant than other volatiles. And when VOC's are considered, the anthropogenic comparment is quite abundant indicating that the area is under anthropogenic influence.

COMPARISON OF TWO FLUX MEASUREMENT TECHNIQUES FOR BIOGENICALLY EMITTED VOC

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Vertical fluxes of a series of monoterpenes emitted by orange trees along the Spanish Mediterranean coast have been measured in the atmospheric surface layer in June 1997 by two techniques simultaneously: the relaxed eddy accumulation (REA) and vertical gradient (VG) methods. In both approaches, the products to be analysed were trapped on Tenax-TA coated steel tubes and subsequently analysed by GC-MS. The concentrations obtained were treated in combination with micrometeorological observations made by sonic anemometers. Regarding the gradient measurements, fluxes were calculated using concentration differences between the three possible combinations of the three sampling levels located at 4, 7 and 12 m a.g.l. The three values were generally similar and showed a good agreement with those obtained by the REA method. This seems to indicate that the influence of chemical destruction on the observed monoterpene fluxes was not important. This effect can be investigated by calculating the Damkohler number, i.e. the ratio of the dynamic and chemical characteristic timescale by considering that the chemical destruction pathways for monoterpenes occured through reactions with ozone and OH, the values obtained for the Damkohler number were all lower than 0.05, confirming the low influence of chemical destruction on the flux measurements.

APPLICATION OF THE MESOSCALE METEOROLOGY-CHEMISTRY MODEL TVM-LCC/RACM TO THE STUDY OF BIOGENIC EMISSIONS

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Due to its deleterious effect on human health, agricultural crops and forest ecosystems, tropospheric ozone continues to be of significant concern world-wide. The fundamental question to solve in environmental atmospheric chemistry is the following: "To reduce tropospheric ozone levels in impacted urban, suburban and rural areas, should one control VOC, NOx, or both simultaneously, and to what degree?". The same question holds for other air polluting compounds, such as benzene, PAN, PAH and organic particles). The potential importance of biogenic VOCs (in relation to anthropogenic VOCs) for ozone control strategies is evident from the suggestion that the BVOC emissions may be so large that even a 100 % control of AVOCs would not be sufficient to meet air quality standards. In the present work TVM coupled to two different chemical schemes LCC and RACM is applied over the region of Burriana (near Valencia) to model the data collected during the june 1997 campaign. The evolution of the ozone and other compounds is described and the impact of different biogenic emissions is evaluated.

A CONCEPTIONAL MODEL TO ASSESS BIOGENIC AND ANTHROPOGENIC OZONE FORMING POTENTIALS FOR MECKLENBURG-VORPOMMERN, GERMANY

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Based on the knowledge about the genesis and about the spatial heterogeneity and temporal variability of ozone episodes at the southern Baltic Coast a conceptional model of ozone forming potentials is derived. Starting point for this model is the landscape ecological axiom formulated by the authors. Characteristics and assessments of the weather situation, of thermal affected air changing processes and the ecosystem patterns are inputs of the model. Especially biogenic precursors (VOC) are reponsable for the autochtone ozone production in Mecklenburg-Vorpommern usually at light winds and intense solar radiation. The background NO_x may not be important because it refers to supraregional processes of distribution. Emission rates of VOC of various crops and trees in Mecklenburg-Vorpommern were estimated during the POPCORN-project 1994. Wind speeds and wind directions formed a „cachment" for die formation of ozone at local level.With the help of a fuzzy-system including emission rates, proportionate area of high emitting plants and emission rates of anthropogenic sources different ozone forming potentials are developed for three representative sites. Furthermore statistic parameters of stochastic time series of the ozone concentration within ozone episodes and the synchronous meteorological data are necessary for the fuzzy-model. Digital maps of ozone forming potentials should be a constituent of subregional landscape ecological frameworks in Mecklenburg-Vorpommern.

LAND USE CHANGE AND BIOGENIC HYDROCARBON EMISSIONS FROM MEDITERRANEAN AND SAVANNA LANDSCAPES

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Vegetation produces and emits hydrocarbons that have a significant impact on the chemical composition of the atmosphere. The magnitude and relative abundance of these compounds are highly dependent on plant species distributions and vary considerably among different landscapes. Changes in species composition and total biomass density can therefore result in significant changes in landscape-average hydrocarbon emission rates. We consider how human activities have modified hydrocarbon emissions from Mediterranean and savanna landscapes in Europe, North America and Africa. Changes in species composition include decreases in native species, increases in a native species, and the introduction of exotic species. Human activities that change plant species composition include the obvious, such as the clearing of native vegetation followed by extensive planting of introduced agricultural plants, and less obvious ones resulting from grazing and other land management practices. Estimates of current and historical plant species distributions are combined with emission factors for individual plant species to determine changes in landscape-average emission rates. The results indicate that the relative composition of the total VOC emission can be greatly changed. In addition, it is estimated that human activities in some landscapes have lowered total emissions while higher total emissions have resulted in other landscapes.

SEASONAL VARIATION OF THE VOC EMISSION RATES OF BOREAL BROAD-LEAFED TREES

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The monoterpene, isoprene, and light hydrocarbon emission rates of few broad-leafed trees (e.g. silver birch (*Betula pendula*) and downy birch (*Betula pubescens*)) were measured during two growing seasons 1996 and 1997 in the boreal vegetation zone using the dynamic flow-through technique. Monoterpene emission rates were significant soon after the leaves had opened in May. After few days the emissions decreased considerably being very low in June. The emission rates increased again at the end of June when the leaves were fully expanded. Birches continued to emit terpenes until the end of August. Compared to silver birch the emission rates of downy birch varied more from day to day both in quantity and quality. The main terpene species emitted were α-pinene and 3-carene in May and June and ocimenes and sabinene in July and August. The terpene emissions were dependent on temperature. Silver birch emitted small amounts of light hydrocarbons (ethene, propene and 1-butene) soon after leaves had opened. Birches emitted only minor amounts of isoprene.
This work is part of the BIPHOREP-project aimed to quantifying biogenic VOC emissions in the boreal vegetation area.

TERPENOID EMISSION FROM *CITRUS SINENSIS* (L.) OSBECK UNDER DROUGHT STRESS

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In the Mediterranean area orange plantations are common. Since periods of soil dryness are typical for the climate of Southern Europe, drought stress can be assumed to be a factor influencing the overall emission of terpenoids in this area. In order to investigate the relationship between the water status of *Citrus sinensis* and terpenoid emissions, monoterpene and sesquiterpene emission rates from a branch of a young orange tree were followed during a drought treatment and subsequent recovery. Terpenoid emissions from *Citrus sinensis* leaves consisted mainly of the sesquiterpene *beta*-caryophyllene and the monoterpene *trans*-ocimene, other terpenoids were found in traces. During high light and temperature periods both compounds were emitted at highest rates, whereas nearly no emission was found in the dark. The emission pattern in response to changes in light and temperature was found to differ between *beta*-caryophyllene and *trans*-ocimene: During the first nine days without water a close relationship between the emission rate and air temperature was found for *beta*-caryophyllene but not for *trans*-ocimene. The data show that severe drought stress reduces terpenoid emissions from leaves of *Citrus sinensis*. When the leaves lost turgescence the emission rate of *beta*-caryophyllene was only 8.4% and the rate of *trans*-ocimene 6.7% of the maximum rate detected at the beginning of the experiment.

MONOTERPENE EMISSIONS FROM RAPE: LIMITATION BY DMAPP / IPP AVAILABILITY

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Monoterpene emissions from several plant species are affected by temperature as well as by light intensity. These dependencies are described by a general algorithm considering two different mechanisms: Emissions from pools as well as emissions in parallel to biosynthesis (Schuh et al. 1997). For rape plants we found that the emissions in parallel to biosynthetic activity by far exceed those from pools. Isoprene and monoterpene emission rates are correlated and the emissions of all compounds are described with the same values for the individual parameters of the algorithm. We conclude that the monoterpene emissions from rape are limited by steps until DMAPP / IPP production. Thus, for light fluxes far above the compensation point of CO_2 uptake, the yield of DMAPP / IPP production rate can be calculated by comparing the total carbon emission (isoprene, mono-, and sesquiterpenes) to that of CO_2-uptake. This yield is independent of light intensity but dependent on temperature. At a given temperature a constant fraction of the carbon taken up by rape plants is used for the biosynthesis of monoterpenes. Increasing temperature leads to an increase of this fraction. Exposure of rape plants with ozone at high concentrations leads to a significant decrease of this yield implying that the biosynthetic pathways of monoterpene production in rape plants is directly affected by ozone exposure at high concentrations (130 - 180 ppbV).

A smog chamber study on the formation of aerosol and gaseous products by the photo-oxidation of monoterpenes

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A series of experiments have been carried out in the European Photoreactor (EUPHORE) in Valencia, Spain, to study the formation of aerosol and gaseous products from the photo-oxidation of α-pinene, β-pinene and limonene in air in the presence of high or low NO_x-concentrations. Also the reactions of the same terpenes with ozone alone were investigated as well as the influence of humidity and of addition of an OH-scavenger on these reactions. In some experiments, an inorganic seed aerosol was added. The initial terpene concentrations were between 10 ppbV and 1000 ppbV. Aerosols were characterized with respect to their number and size distributions, their hygroscopicity and some of their chemical components. The results allowed to study the equilibrium between semivolatile products in gas phase and in particles which lead to an increase in the fractional aerosol yield with increasing amount of reacted terpene. The particles formed by photo-oxidation as well as by ozonolysis were found to be only slightly hygroscopic.

BIOGENIC VOCS IN CONTINENTAL NORTHERN EUROPE - CONCENTRATIONS AND PHOTOCHEMISTRY

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Biogenic emissions of volatile organic compounds and their role in the photochemistry have been a special research focus in northern Europe during the past two years. The project 'Biogenic VOC emissions and photochemistry in the boreal regions of Europe' (BIPHOREP) aims at the quantification of biogenic VOC emissions and their effect on photochemistry. This presentation gives an overview of ambient air concentrations of biogenic and anthropogenic light hydrocarbons and monoterpenes at representative sites. Concentrations of biogenic species show a strong midsummer maximum which is consistent with the seasonal cycle of emissions. Factor analysis of the concentrations measured during the growing season clearly discriminates between anthropogenic species with different lifetimes and the biogenic ones. The effect of biogenic species on photochemistry was studied using a photochemical trajectory model. In modelling scenarios the air mass was advected over forested regions and also over regionally important anthropogenic sources giving varying levels of biogenic and anthropogenic precursors. Results of the model runs will be presented as development of concentrations of the so called "indicator species", showing the relative importance of anthropogenic and biogenic species and the VOC or NOx sensitivity of ozone formation.

A REA SYSTEM FOR MEASUREMENTS OF VOC FLUXES

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The relaxed eddy-accumulation (REA) system described here is unique in its design: it has the collecting devices (e.g. tenax tubes) in front of the REA switches and the sampling pumps while at the same time maintaining a steady flow through the collectors. This is realized by having two primary flow lines (teflon tubes) with relatively large flow rates subject to the switching of the REA system. The sample air is then drawn at a constant and much lower rate from these lines. The software driving the REA system is also unique: it uses a dynamic "dead band" the width of which is a fraction of the current turbulence level. The empirical consequence of this is that the so-called β-factor becomes a constant, independent of for example atmospheric stability. Examples of VOC fluxes measured above an orange plantation during the BEMA-97 campaign in Burriana, Spain, is presented.

STUDY OF MATTER AND ENERGY TRANSFERS BY AIRPLANE MEASUREMENTS DURING THE BEMA CAMPAIGN (BURRIANA - SPAIN)

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One of the aims of BEMA campaignperformed in BURRIANA (Spain) is to quantify the influence of natural hydrocarbon emitted by the vegetation on the atmospheric chemistry, especially on variations of ozone. To reply to this objective, it is necessary to know the different terms of the bilan equation , as well as initial conditions and boundary conditions of the studied area, influenced by the coastal breeze development. Airplane measurements of field concentration and field fluxes have been achieved during the campaign. We present the methodology developed for the measure of vertical turbulent fluxes from aircraft, considering the heterogeneity of the experimental zone. The fluxes surface measurements near the ground allow to estimate the term of deposition of the ozone on the ground and the vegetation. Flux measurents atop the internal boundary layer allow to estimate the intensity of matter transfers inside the breeze cell. Fluxes of ozone are compared to fluxes of particles , latent and sensitive heat.

ENCLOSURE APPROACHES FOR THE DETERMINATION OF TERPENOID EMISSIONS FROM VEGETATION

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Within the BEMA project (Biogenic emissions in the Mediterranean Area) we investigated the emission of isoprene, monoterpenes and some sesquiterpenes from a variety of tree species, such as *Quercus ilex*, *Pinus pinea* and *Citrus sinesis*. Within these studies different enclosure techniques (cuvettes) were used. The tree species differed significantly in terms of emission quantities as well as qualities. We will present emission data obtained with cuvettes flushed with air of different qualities such as ambient air, purified (activated charcoal) air and ozone free air (Ozone scrubber). The data show the need to protect highly reactive terpenoid species against ozonolysis already within the cuvette in order to detect their emission. This need is especially important to describe the primary emission rates from trees like Orange and Pine, as these tree species were found to release the most reactive terpene species. Our findings are discussed with respect to the chemical reactivity of the terpenoid species emitted, and to implications for emission inventories and for measurements of BVOC fluxes above canopies.

ECOPHYSIOLOCICAL CHARACTERIZATION OF *CITRUS SINENSIS* (L.) OSBECK AND RELATIONSHIPS WITH TYPE AND AMOUNT OF BIOGENIC EMISSIONS

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In a previous study we got some hints that emission rates are related to functional indices of drought adaptation. Plant species emitting monoterpenes or isoprene from current metabolism can well be separated from plants emitting from internal reservoirs. This work reports the ecophysiological and emission data obtained during the B.E.M.A. campaigns held in Burriana (Spain) on orange groves which highlight one of the factor that could influence the type and amount of biogenic emissions. Moreover this knowledge could be useful in modelling studies based on a integration approach at different scales. In particular this factor is related to the leaf/canopy level and can be synthesized in the low photosynthetic performance that seems to characterize the species. Moreover, the low transpiration rate may influence the leaf temperature and related processes. In general, a low value of E/A ratio, i.e., emission rates per assimilation rates, for citrus are related to an efficient control of leaf transpiration notwithstanding the periodical flooding of the orange grove that kept the soil in a good water condition. The relationships between ecophysiological results and terpenoid emissions are also discussed.

OBSERVATIONS OF BIOGENIC AND ANTHROPOGENIC NMHC IN ATHENS DURING THE PAUR CAMPAIGN

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Within the PAUR campaign measurements of on-line NMHC including both biogenic and anthropogenic compounds took place at a suburban site in the Greater Athens Area during May and June 1996.
Due to rather strong and persisting NW-wind patterns during the entire PAUR campaign overall low NMHC mixing ratios compared to previous studies in the Athenian Area were encountered. However, this gives the opportunity to investigate "background" situations within an urban area that not directly located in the urban plume under these specific almost constant meteorological conditions. In addition this site may also be influenced by rural air masses. These air masses usually are marked by constant background levels of ozone. Thus observations of diurnal variations of biogenic and anthropogenic NMHC primarily reflect different emission scenarios throughout the day. Relationships between specific NMHC will be shown and their possible impact on the formation of photooxidants will be discussed.

A BIOGENIC VOC EMISSIONS INVENTORY FOR GREECE

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A biogenic emissions inventory with a 5X5 km spatial resolution for isoprene and monoterpenes for Greece was constructed, using the GRASS4.1 Geographical Information System (GIS). The GIS system calculates the emission rates of monoterpenes and isoprene from vegetation spatial speciation and species biomass, spatial climatological solar radiation and temperature values, and emission/correction factors. The temporal resolution is one hour. Two different methodologies were applied for the calculation of emissions: The first uses the emission factors of Guenther et al. (1994) and the correction factors of Guenther et al., (1991) and Pierce et al. (1990), while the second one utilises the CORINAIR (1988) methodology. Typical emission rates calculated using the former emission/correction factors for forested areas for isoprene and monoterpenes were 0.5-2 kg km^{-2} day^{-1} and 5-20 kg km^{-2} day^{-1}, respectively, during January and 10-50 kg km^{-2} day^{-1} and 10-50 kg km^{-2} day^{-1}, respectively, during July. Higher values than the ones above are calculated for a number of forested areas of limited extend. The application of the CORINAIR methodology leads to unrealistically high values (up to two orders of magnitude higher than the former methodology). Results on the temporal and spatial variation of biogenic emissions in Greece are presented for the months of July and January.

VERTICAL FLUXES OF MONOTERPENES ABOVE A SCOTS PINE STAND IN THE BOREAL VEGETATION ZONE

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In many parts of the boreal vegetation zone biogenic emissions of VOCs are estimated to exceed the anthropogenic emissions. Due to the abundance of coniferous trees monoterpenes are of great importance to the VOC reactivity in northern Europe.
As a part of the BIPHOREP-project, a micrometeorological measurement campaign was conducted in eastern Finland on July and August 1997. The forest in the measurement site was composed mainly of Scots pine (*Pinus sylvestris*). The vertical fluxes of monoterpenes were measured by the micrometeorological gradient method. Monoterpenes were sampled into Tenax absorbent using two automated samplers situated above the forest canopy. The turbulent exchange coefficient was obtained by universal flux-gradient relationships using eddy covariance measurements of momentum and sensible heat fluxes.
The most abundant monoterpene at the measurement site was α-pinene. Other monoterpenes observed include carene, β-pinene and camphene. The vertical fluxes of these compounds will be presented and compared to the meteorological factors.

EFFECT OF LIGHT AND TEMPERATURE ON THE EXCHANGE OF GASEOUS FORMIC AND ACETIC ACID FROM ORANGE FOLIAGE (CITRUS SINENSIS L.)

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It is widely accepted that gaseous acids can be emitted as well as be taken up by foliage of plants but little is known about the influence of environmental factors on the exchange process. In a laboratory study we investigated the effect of temperature and light on acid exchange of orange foliage by means of a dynamic enclosure system flushed with humidified air containing only low amounts of acids. Mixing ratios of acids inside enclosure ranged from 0.1 to 3 ppbv and emission rates at 30 °C and 1000 µmol photons m^{-2} s^{-1}were about 0.05 nmol m^{-2} projected leaf area s^{-1} for acetic acid and about 0.1 nmol m^{-2} s^{-1} for formic acid. No significant net acid uptake could be observed. Emission responses to temperature and light treatments showed variable patterns especially for formic acid but a clear positive influence of light could be established. Our findings indicate that acid release is positively related to leaf water flux and further promoted by a process expressing diurnal rhythm.

OA16

A TEMPORAL-SPATIAL SOLAR RADIATION MODEL TO DRIVE BIOGENIC EMISSIONS FROM SPARSE VEGETATION AND OVER COMPLEX TERRAIN

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The diurnal and seasonal emission course from plants is controlled by light and temperature. The pattern of light incident on a surface changes not only temporally but also spatially. This is most obvious in cast shadows. To evaluate the effects on the amount of BVOCs caused by the 3-dimensional surface, a profound solar radiation model (SORAM) was set up within a GeoInformationSystem. Surfaces either representing a canopy, a stand or a terrain are input as digital elevation models. Routinely measured meteorological data are used to determine the transmissivity of the atmosphere. The limitation of the horizon is accounted for as well as the cloud coverage paying appropriate attention to the diffuse component of radiation. Direct and diffuse radiation are separately handled within the light extinction module of the model. Temperature values can be linked to the radiation output enabling the modeling of biogenic emissions according to the light and temperature regime. Results are presented for the BEMA-testsites including comments on the database and algorithms used. Finally, the results are compared to considering a 2-dimensional surface only and the sensitivity of the model shown in regard to the suface's slope and orientation.

SEASONAL CHANGES IN AMOUNT AND COMPOSITION OF MONOTERPENES EMITTED BY YOUNG PINUS PINEA TREES

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The accuracy of emission inventories estimating the annual release of terpenes from vegetation, is partly limited by our insufficient knowledge of the natural temporal variation of emissions. Up to now, it is simulated in all inventories by models depicting the short-term effects of light and temperature, but neglecting long-term effects like seasonality. We studied the emission development of young *Pinus pinea* trees during a 16-month enclosure and compared the results with 3 current models on light and temperature influences. Total annual amount per leaf area was about 1.3 mmol m^{-2} a^{-1}. Mean daytime emission rates were about 1 pmol m^{-2} s^{-1} in mid winter and about 200 pmol m^{-2} s^{-1} in mid summer. Seasonal changes in emission amount were accompanied by substantial changes in emission composition. Emissions during sunlit hours in summer were dominated by reactive acyclic terpenes that were not emitted at night and in winter. Emission normalisation by models reduced the winter to summer difference by a factor of 10 only, indicating that a great part of the long-term variation was due to seasonal changes of the emission capacity. Thus seasonality can cause considerable errors when emission rates measured in one season are extrapolated for the whole year. In case of *P. pinea*, prediction of annual emissions based on summer measurements would lead to an overestimation of at least 100 %.

MONOTERPENE EMISSION FORM SOILS IN ORANGE PLANTATIONS IN THE VALENCIAN CITRUS BELT, SPAIN.

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During a campaign of the BEMA-project (Biogenic Emissions in the Mediterranean Area) in the Citrus belt of Valencia, Spain, emission rates of monoterpenes from the soil were determined in two orange plantations using the dynamic cuvette technique combinded with online and off-line GC-technique. Main tree species were Citrus sinensis and Citrus clementii. The typical pattern of monoterpenes from the soil surface were: limonene >> sabinene > p-cymene/1,8 cineol > myrcene > d3-carene > α-pinene > ß-pinene. By comparing different soil plots it became obvious that the emission from soil was caused by the organic layer on the surface. After removing the organic material the emission of limonene was reduced to 26 %. This remaining emission can be traced to adsorbed terpenes on particles in the upper soil layer. After carrying off 3 cm of the upper soil no emissions were measurable.The terpene emission from detached fruits laying on the ground compared to the emission of detached leaves on the ground was 3.5 times higher. Both in Orange and Mandarin fields, the emission rates from soils covered with representative litter under the tree canopies were about 100 times higher than from bare soils between the rows. The emission of terpenes was mainly controlled by the surface temperature. Our findings are discussed with respect to the assessment of overall emissions from orange fields.

THE C1- AND C2- ORGANIC ACID AND ALDEHYD EXCHANGE OF LICHENS IN THE BOREAL ZONE OF EUROPE

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Within the BIPHOREP project (Biogenic VOC emissions and photochemistry in the boreal regions of Europe) we focus on the role of lichens in trace gas exchange between atmosphere-biosphere. Lichens are one of the most characteristic elements of boreal forests and contribute significantly to living vegetation biomass, increasing from the boreal towards the arctic region. In contrast to numerous studies on trace gas exchange with boreal trees lichens are only poorly investigated. Therefore, we focused on the exchange of organic acids and aldehydes between lichens and atmosphere. Several lichen species have been screened under climate chamber conditions. Controlled simulation of natural conditions was important to overcome the problems that result from trace gas measurements with poikilohydric organisms in cuvette enclosures. Using a cryogenic trapping technique for organic acids followed by Ion chromatography analysis we detected a deposition of formic acid to lichens depending on thallus water content. Investigation of Aldehyde exchange (DNPH-cartridges, HPLC) revealed a small and time limited emission of acetaldehyde. We will discuss first results and give estimates for the potential contribution from the lichen vegetation to the boreal forest exchange of these VOCs.

AEROSOL FORMATION IN GAS-PHASE MONOTERPENE OZONOLYSIS AT NEAR-ATMOSPHERIC CONCENTRATION

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Ozonolysis of the monoterpenes α-and β-pinene, limonene, terpinolene, sabinene, and 3-carene was performed at low initial concentration (4 - 50 ppbv monoterpene). The formation of particles with a diameter > 10 nm was monitored with a condensation particle counter (TSI 3010). It was found that a conversion of less than 2 ppbv is sufficient to observe the formation of particles in case of sabinene, β-pinene, and limonene. In order to examine a possible relationship between monoterpene structure and its nucleation rate, the onset of particle formation for the different monoterpenes was investigated at comparable initial rates ($k(O_3)*[\text{monoterpene}]_0*[O_3]_0$ = constant). The ability of the different monoterpenes to form condensation particles was found to be more efficient for exocyclic (e.g. β-pinene) than for endocyclic monoterpenes (e.g. α-pinene). This structure-relationship was also observed for the exocyclic model compound methylenecyclohexane, forming much more particles than the endocyclic 1-methylcyclohexene and cyclohexene. The identification and quantification of the products of monoterpene ozonolysis was performed at high initial concentrations (3 ppmv monoterpene) and analyzed by FTIR and ion-chromatography. The formation of dicarboxylic acids and their role as possible aerosol precursors will be discussed.

OA17 Climate variability: models and observations (joint with SE) Overview session

Convener: Komen, G.J.

CLIMATE VARIABILITY DEDUCED FROM THE MODERN AND PALEOCLIMATIC RECORDS

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CLIVAR and EUROCLIVAR diagnostic studies will rely upon existing records of instrumental data and proxy-data derived from paleoclimatic indicators. As the instrumental record is short and documents only a few examples of climatic events with interdecadal time scales, diagnostic studies of climate variability will rely, in a fundamental way, upon paleoclimatic proxy-data. The seasonal to centennial variability of the climate system can be deduced by annually-laminated sediments, corals which grow at rates of millimeters per year and produce annual growth bands, tree rings which develop in areas of large seasonality, and ice records of $\delta^{18}O$, δD and conductivity. The decadal to centennial variability of the climate system is recorded in polar and tropical ice cores, in loess sediments and in specific areas of the world ocean characterized by extremely high accumulation rates. A strategy was established by the EUROCLIVAR scientific committee to make the best use of available data, to generate additional data from meteorological observations (both in the atmosphere and the ocean) and proxy-data, and to assimilate these data in climate models.

CLIMATE CHANGE PREDICTION AND DETECTION USING COUPLED CLIMATE MODELS WITHIN EUROPE

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Anthropogenic climate change studies within Europe using comprehensive coupled climate models have made significant advances in recent years. Recent improvements in models, advances in modelling studies, and some outstanding modelling issues are discussed, illustrated with recent results from Hadley Centre and other European models. Established modelling centres (eg. UK Hadley Centre, DKRZ Hamburg) have built on experience from earlier coupled models to develop new models with higher resolution, better simulations of present-day observed climate, and allowing improved representation of anthropogenic forcings. At the same time, natural and anthropogenic climate forcing factors other than just greenhouse gases (eg. anthropogenic sulphate aerosols, variations in solar output, and past volcanic eruptions) are increasingly recognised as important to include in climate change detection and attribution studies. Uncertainties inherent in the chain between assumptions about anthropogenic emissions and corresponding conclusions from climate models about global and regional climate changes mean that present diversity in modelling approaches is healthy, model intercomparison studies adding value to conclusions from any single model. Improving representations of clouds and eliminating artificial flux adjustments are two related focuses for model improvement. Model predictions are vital tools for the detection and attribution of climate change. Findings from a recent Euroclivar workshop on this topic will be summarised.

EUROPEAN AND ATLANTIC CLIMATE VARIABILITY

Mojib Latif (Max-Planck-Institut fuer Meteorologie. Hamburg. Germany)

Natural climate variability in the extratropics occurs on all time scales. from interannual to centennial. and beyond. These variations. typical for the variability of European climate. are influenced by the oceans. They affect mean conditions but also the occurrence of extremes. Understanding and - if possible - prediction of these variations is important. also for the detection of anthropogenic climate change.

It is recommended that Europe develop a major modelling and observation programme to improve understanding of the role of the Atlantic Ocean in climate. This requires improved observation and understanding of the modes of climate variability in the Atlantic region and an assessment of the degree to which these are predictable. The required concerted effort in ocean observation. improvement in atmospheric analyses and palaeo reconstructions. coordinated modelling and process studies will be outlined.

OA17 Climate variability: models and observations (joint with SE)

01 West African monsoon studies

Convener: Thorncroft, C.D.

SCALE INTERACTIONS AND GLOBAL TELECONNECTION PATTERNS.

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The climate in a region can be considered to be the ensemble of the weather systems that affect that region. The behaviour of these weather systems may be modulated on a range of timescales often associated with the lower frequency variability of the oceans. In turn. these weather systems themselves may influence that low frequency variability. In the tropics there is increasing evidence that scale interactions involving atmospheric intraseasonal variability. particularly associated with the Madden-Julian Oscillation and Westerly Wind Bursts. may affect the development of El Niño. The impact of El Niño on the climate is profound due to teleconnection patterns which extend over the entire globe. These teleconnections are recognized as major modes of climate variability.

During the early months of 1997 the tropical Pacific Ocean underwent a dramatic transition from La Niña conditions in December 1996 to a major El Niño by June 1997. The evolution of this event and its impact on global weather will be used to illustrate the importance of scale interactions and global teleconnections as future priorities for research within Europe.

CLIMATE MODELS: CURRENT UNCERTAINTIES AND FUTURE PROSPECTS

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Numerical Models constitute an essential tool of our discipline. necessary both to understand the complexity of the natural fluctuations of climate and to predict its future evolutions. at any time scale. Their performance . resolution. complexity has been steadily increasing over the last decades. Most centers now run coupled ocean/atmosphere models. and the inclusion of chemical or biochemical models in both th ocean or the atmosphere is in progress. Yet the basic uncertainty attached to future climate predictions (in response to the anthropogenic greenhouse effect for example) has not been diminished. By many respects the results of models designed independently is our only measure of this uncertainty. At the same time the large number of models may be felt as some uncessary waste of energy by the scientific community if it is not used in some consistent way. The presentation will review some of the intrisic difficulties with which modellers are being faced and will take the example of cloud feedbacks to illustrate the possible benefits of common model intercomparison or model validation exercices. The main conclusions of the Euroclivar panel concerning model studies will then be reviewed and opened to discussion.

OA17

BLOCKING SIMULATION IN GENERAL CIRCULATION MODELS WITH DIFFERENT RESOLUTIONS

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Different outputs of three general circulation models (CNRM ARPEGE, UKMO and MPI ECHAM4), integrations at different resolutions (up to T106 equivalents triangular truncation) but with the same sea surface temperature, have been analysed from the point of view of blocking simulation. The analysis has been developed with the help of an objective blocking index based on the quantification of the zonality of the flux. For each model integrations. systematic errors and model variability have been assessed. In general all the model runs tend to underestimate blocking frequencies especially in the Pacific. where blocking appears more dependent on the oceanic forcing rather than on the internal dynamics of the atmosphere. but their behaviours as the resolution increases is very different. ARPEGE model is characterised by a strong tendency to decrease the already too low blocking frequency even if the position of maxima of variability (both low and high frequency) is better reproduced in the high resolution run. On the contrary ECHAM4 model shows an improving. as the resolution increases. both in space and in time simulations but only on the Euro-Atlantic sector. In particular the model reproduces realistically the interannual variability of this sector. The UKMO model has been found to be rather insensitive to model resolution variations .Additionally. it is the only model which overestimates somehow the frequency in the Euro-Atlantic sector at all resolutions. The yearly cycle is improved by increasing resolution but not the same can be said for the interannual variability.

LARGE-SCALE DYNAMICS AND THE WEST AFRICAN MONSOON

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The West African monsoon is discussed from the perspective of the large-scale atmospheric hydrodynamics. Studies with a general circulation model and diagnosis of NCEP and ECMWF reanalysis products are used to understand how and why the low-level monsoon flow and the African easterly jet are forced, and to investigate their role in determining the precipitation climatology. Moisture transport and convergence within the monsoon flow is examined through a consideration of the moisture budget. The vorticity budget is used to explain how the flow across the Guinean coastline balances vortex stretching due to mid-tropospheric condensational heating, thereby maintaining the precipitation. The African easterly jet, which is the result of strong surface heating at Saharan latitudes, contributes to the total vertically-integrated moisture budget over West Africa through its association with a moisture divergence maximum near 700 mb. This connection results in added sensitivity of the West African climate to land and sea surface temperatures, since the jet is sensitive to the large-scale meridional temperature gradient. The large-scale dynamics of West Africa is compared with that of East Africa to suggest reasons for the observed similarities and differences in precipitation variability.

Rain event climatology in West Africa : Comparison from in situ and GCM outputs

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West Africa has suffered from a continuous drought for the past 30 years. In order to assess the impacts of this drought onto the processes conditioning the continental water cycle, the rainfall variability has to be studied at smaller scales than the usual monthly and yearly scales. Recent works based on in situ observations suggest that, in the Sahel, there is a dominant co-fluctuation between the number of rainy events and the cumulative rainfall at various time scales (see Lebel et al., this session). This has strong implications for the hydrological cycle and it is therefore important to verify whether this feature is reproduced in GCM's used to evaluate the impacts of climate fluctuations onto the water resources in West Africa. A first step in that direction has been taken by investigating how the GCM rain event characteristics vary when averaged over two contrasting periods : the wet years 1951-1970 and the dry years 1971-1990. The fluctuations observed in the GCM outputs are compared to those recorded over the same 2 periods by the regional network covering a 12°(latitude) x 15° (longitude) window. The two parameters considered here are the number of events and the mean event rainfall. It is found that the number of events produced by the GCM has decreased significantly during the dry years, as compared to what it was during the wet years. In that respect, the GCM conforms to the observations. On the other hand, the average characteristics of the GCM rain events are somewhat different from those of the observed rain events. The various reasons, mainly the sampling characteristics and the GCM parametrisation, that may explain these differences are discussed.

DIFFERENT REGIMES OF EASTERLY WAVES OVER WEST AFRICA AND TROPICAL ATLANTIC (1979-1995)

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NCEP/NCAR reanalyses are used over the period 1979-1995 to investigate the easterly waves activity over West Africa and the tropical Atlantic and its relationships with rainfall and convection. Three main band-periods are pointed out in spectral analyses of meridional wind at 700 hPa : 3-4 days, 4-5 days and 6-9 days. The 3-4-day and the 4-5-day regimes correspond to the well known easterly waves activity respectively south and north of the African Easterly Jet. The 6-9-day regime corresponds to similar easterly waves north of the jet but with stronger associated anticyclonic circulations behind the wave trough. The modulation of rainfall and convection by these two wave regimes is investigated by using ORSTOM and NCEP/NCAR daily rainfall amounts and three hourly ISCCP satellite data. Energetic computations are also performed to discriminate the two wave regimes.

Numerical study of interactions between a squall-line and an easterly wave

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The relationship between convection and easterly waves is one of the key factors for understanding the west African monsoon. Up to now these interactions has been mainly studied owing to composite analysis of observations (Reed et al 1977) and to idealized modelling studies (Simmons 1977). On the other hand explicit resolution of convective systems such as squall lines, was restricted to limited domains of simulation without any realistic treatment of the initiation stage and of forcings by larger scales. Recent progresses in modelling and computers allow us now to treat these scale interactions more explicitely for some case studies.

Here the atmospheric simulation system Méso-NH is used to simulate a squall line associated with an easterly wave and observed on the 22 august 1992 during HAPEX-SAHEL in Niger. Two types of simulations are performed. First meso-β ones (30 km resolution) initialized by the ECMWF analysis and fine scale surface conditions, to represent the dynamics of the easterly wave owing to the use of a convective scheme. These simulations are then used to forced and initialize the squall line explicitely resolved (2 km) by a second model nested in the first one. We will present the validation of this approach on the base of comparisons with available observations (satellite and radar imagery, precipitation and convection footprints as observed by HAPEX-SAHEL ground stations)

SIMULATION AND PREDICTION OF THE WEST AFRICAN MONSOON

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One objective of the European Union PROVOST experiment is to estimate potential dynamical seasonal predictability given ideal surface boundary conditions on a global scale. To this end, the UK Met Office Unified Model (at climate resolution) has been integrated in 9 member ensembles initialized at 24-hour intervals over 15 Boreal summer seasons (June to September) from 1979 to 1993. Initial conditions from the ECMWF reanalysis as well as SST anomalies from the UKMO GISST and Reynold's OI data sets were used in all the experiments.
Tropical West Africa is one region chosen in order to test the capability of providing seasonal forecasts. Probabilistic and deterministic rainfall predictability appear to exist over this region in the PROVOST simulations. The dynamical model is able to capture the interannual rainfall variability reasonably well but underestimates magnitudes. Since 1994, dynamical forecasts have been produced at UKMO for tropical west Africa, the difference from the PROVOST runs is that persisted SST anomalies from May are used throughout. It appears likely that there is minimal loss in predictability through the use of persisted anomalies if the results from 12 boreal winter and spring experiments can be extrapolated to summer. Assessments of the 1997 monsoon forecast will be presented in both probabilistic and deterministic terms.

VARIABILITY OF THE WEST AFRICAN MONSOON ON INTRASEASONAL AND INTERANNUAL TIME SCALES

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Using 22 years (1974-1996) of twice daily outgoing longwave radiation (OLR) observations and 15 years of ECWMF reanalysis data (1979-1993), the intraseasonal (June-September) and interannual variability of certain components of the West African monsoon (WAM) will be investigated. The focus will be on the intraseasonal and year-to-year variations in the African Easterly Jet and in the associated activity and climatological track of African Easterly Waves (AEWs). The activity and the mean track of AEWs are estimated by local variances of 2.5-8 day bandpass-filtered time series of both kinematic and thermodynamic/moisture variables (e.g., relative vorticity and meridional wind at 700 hPa, OLR and precipitable water). Differences in the obtained AEW statistics as inferred from both types of variables are discussed. Their relation to variations in moisture advection by the low-level southwesterly monsoonal flow and to the rainfall performance of the WAM is shown.

CLIMATE IMPACT OF AIRCRAFT EMISSIONS IN THE UPPER TROPOSHERE. STUDIES WITH A 2D-MODEL

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The climate impact of aircraft emissions was studied with an interactive dynamical-chemical radiative 2D-model based on a standard climate 3D-GCM (ECHAM) and a coupled NCAR chemistry module. The main feature of the 2D-model is a selfconsistent parameterization of the tropospheric eddy heat and momentum fluxes. Sensitivity studies with and without zonally averaged aircraft NO_x emissions will be presented giving a better understanding of the dynamical-chemical interactions and the climatic features of both the background and the disturbed atmosphere. For example, the results show the dependence of the NO_x background concentrations on the composition of downward sinking lower stratospheric air masses and on the tropopause structure in northern winter midlatitudes in the height of the main aircraft emissions injection area.

AUTOMATIC TRACKING OF WEST AFRICAN CLOUD CLUSTERS

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With the objective of building climatological statistics on propagation of African cloud clusters, and studying their morphological and radiative properties, an automatic method for tracking cloud clusters has been developed. Using Meteosat infrared full resolution images, the method allows for tracking systems of size greater than 5000 km2. A cloud cluster was defined as adjacent pixels colder than a brightness temperature threshold. We have chosen several thresholds such as: 213 K, 233 K, 253 K. The method is based on the cluster overlap between two successive images. The algorithm takes into account splitting and merging of clouds, and allows for an objective determination of parameters such as: size, mean temperature, temperature variance, duration, coordinates of the centre of gravity, speed, trajectory, eccentricity etc. In order to use the full space resolution, the study is limited to West Africa from the equator to 20°N latitude and from 25°W to 20°E longitude.
We found some artefacts we have to take into account in the utilisation of the algorithm outputs (border effects, effects derived from the quality of the available Meteosat data set, reliability of parameters in case of split or merging of clouds...). However the processing of several years of data shows that the algorithm is reliable and produces results suitable for the study of convective cloud systems. This has been done over 1993 to 1997. Trajectory, diurnal variation, location of initiation and dissipation, variation of parameters during the cloud life cycle are analyzed. ECMWF analysis are also used to comment the results obtained with the tracking.

INTERANNUAL VARIABILITY OF INTRASEASONAL AND SYNOPTIC WEATHER SYSTEMS OVER WEST AFRICA ON THE PERIOD 1968-1997

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During the drough Sahel period beginning in 1968, the impact of ENSO events on Sahel rainfall has seemed stronger than before. NCEP/NCAR reanalyses are used over the period 1968-1997 to investigate interannual variability of synoptic weather systems like easterly waves as well as intraseasonal scale weather systems like monsoon surges and their impact on rainfall events. We investigate also the possible teleconnections with ENSO variability, especially linked to the heat source in the eastern equatorial Pacific.

PROPAGATION OF THE MESOSCALE STORM FLOW OF WEST AFRICAN SQUALL LINES

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Recent work has shown how the mesoscale flow in the vicinity of a squall line is forced principally by a gravity wave response to the line of convective heating. The vertical profile of temperature and 3D wind in the inflow to a system, which is known to be crucial to its maintenance, is modified to first order by this mesoscale flow. Application of these concepts to the West African region, where squall lines may be propagating at all levels, is particularly interesting, as the wavelike response may evolve upstream of the cloudy region, to precondition the inflow to the storm as well as the anvil region.
As a preliminary step to understanding the propagation of the storm flow upstream of a Sahelian squall line, the nature of the fast linear waves on the African Easterly Jet is described. The structure and dispersion relations for different modes have been computed by numerical solution of a modified Taylor-Goldstein equation. However, it is only through consideration of the forced solutions that the upstream impact of a squall line can be evaluated fully. The impact of upstream modification on the thermodynamic properties of the squall line inflow is discussed, and the implications of inflow modification on overall squall line evolution are considered.

OA17

Rainfall variability in the Sahel : a matter of scales

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Rainfall variability in the Sahel has become notorious due to the lasting drought that started in the end of the sixties. This is the manifestation of a decadal variability mode which has been analysed by various authors using monthly and yearly averages. By averaging over such large time steps, the high frequency modes are lost, although they are of key importance for the hydrologic cycle. Using a combination of high resolution data collected during the 7 years of the EPSAT-Niger experiment and lower resolution data produced by regional networks over longer periods (typically 40 years), it is shown here that the Sahelian rainfall variability displays some common features at different scales ranging from intraseasonal to decadal. The fluctuations of the number of events explain 80% of the fluctuations of the average rainfall at both the decadal and interannual scales. At the intraseasonal scale, the rainfall maximum observed during the core of the rainy season is associated to both an increase in the number of events and an increase of the rainfall efficiency of the large Mesoscale Convective Complexes (MCC's). Tracing the atmospheric circulation patterns that might be linked to the fluctuation of the number of events thus appears as being a major challenge for the West African Monsoon Project (WAMP).

INTERANNUAL VARIABILITY OF SST - TROPICAL CIRCULATION RELATIONSHIP ON THE PERIOD 1968-1997: FOCUS ON WEST AFRICA.

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The NCEP/NCAR reanalyses are used over the period 1968-1997 to investigate the impact of the main modes of SST variability on the monthly mean tropical circulation. In particular we examine the role of ENSO events in the interannual variability of the seasonal rainfallamounts of the West African monsoon. We will look at the different atmospheric responses in surface (SLP, trade and monsoon winds,..) and in the upper levels (velocity potentials,...), and compare these results with previous studies having used less sophisticated observations and modelling experiments.

ON THE EXISTENCE OF WARM CORE AFRICAN EASTERLY WAVES

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The existence of warm core African Easterly Waves (AEWs) north of the African Easterly Jet (AEJ) core has been clarified using radiosonde data and the UKMO global model analysis from the summer and autumn of 1995. Spectral analysis of wind data at Dakar (14.7°N, 17.5°W) and Bamako (12.5°N, 8.0°W) confirms the existence of waves with AEW period (2.5-6 days). At Bamako the AEWs were characterised by maximum amplitudes at the level of the AEJ whereas at Dakar the waves were characterised by maxima at low-levels. Strong low-level AEW amplitudes on the northern flank of the AEJ were also seen in the UKMO analyses. These low-level amplitudes extended over the ocean but displaced south of the land maximum. The low-level amplitudes arise in association with baroclinic interactions between the negative meridional potential vorticity (PV) gradient in the jet core and the positive low-level gradients of potential temperature, θ, enhanced by the presence of low static stability air north of the AEJ. The warm core waves follow the θ gradients over north Africa in contrast to the 700mb waves that follow the PV gradients that exist at the level of the AEJ. Lag correlation analysis shows that there is strong coherence between the warm core AEWs and the well-known cold core AEWs that propagate south of the jet.

CHARACTERIZATION OF SAHELIAN RAINFALL SPATIAL VARIABILITY AT A SCALE BETWEEN 1 AND 10 KILOMETRES : THE ARCOL EXPERIMENT (REGION OF NIAMEY, NIGER)

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Since 1988, the EPSAT-Niger experiment (Estimation des Précipitations par SATellite au Niger) has been carried out in a semiarid area near Niamey (Niger) to improve the understanding of the precipitation systems of Sudano-Sahelian Africa and to develop operational rainfall estimation algorithms for this region. This experiment is based mainly on the survey of a very dense raingauge network (30 to 110 raingauges) laid on a regular grid covering an area of 16 000 km^2. The first results pointed out different parameters which govern the quality and the climatology of the rainy season. Among those,the link between the number of mesoscale convective systems which represent the biggest part of annual rainfall and the total seasonal rainfall. To have a new understanding of these mesoscale systems, in 1993, a new raingauge network covering an area of 600 km^2, based on 6 parallel lines of about 70 raingauges (ARCOL Experiment - A la Recherche des Cellules Orageuses des Lignes de grain) was set up. Theses lines are oriented more or less North-South and are perpendicular to the main direction of circulation of these convective systems. For each line, the distance between the raingauges is about 1 kilometre. This particular network allowed to study the sahelian rainfall spatial variability at a scale between 1 and 10 kilometres and furthermore, it improved the knowledge of the internal mechanisms of squall lines (particular mesoscale convective system with a structure of the convective front very well defined, oriented North-South, and a preferential path East-West with a speed of about 50 km/h). For this last part, the network allowed to show the size of the basic convective cells (about 1-2 kilometres) which are very intensive, and allowed to follow their displacement.

DECADAL SAHELIAN RAINFALL ESTIMATION OVER AN AREA OF 1 DEGREE SQUARE : CHARACTERIZATION OF THE 'GROUND TRUTH' ACCORDING TO THE RAINGAUGE NETWORK DENSITY.

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The duration of the rainy season in the sahelian zone is about 5 months (may to september). The precipitations resulting from the monsoon flux which moves toward the north at this period are mainly composed of convective systems. These rainfall show a high spatial variability. The regional raingauge network in the Sahel is very sparse (1 to 5 raingauges over 10 000 km^2) hence the mean rainfall estimation over a specific surface is very difficult. Other methodologies to estimate the rainfall over areas are used like infra-red measurement from geostationnary satellite which have a good resolution in time and space, but at the present time the estimation algorithms do not show a good agreement with the measured rainfall on the ground in the Sahel. In addition the spatial variability of rainfall and the weak density of raingauge network do not allow a good validation of the satellite data because there is not a good 'ground truth'. However, in the region of Sahel, a good spatial estimation of rainfall would be necessary to follow the crops and to prevent possible starvation. In that case, a rainfall estimation at a regional scale (degree square) and at a time scale of ten days could be enough. The EPSAT-Niger Experiment (Estimation des Précipitations par SATellite au Niger), localized in the region of Niamey is based on the survey of a very dense raingauge network which presents a regular grid over an area of 16 000 km^2. Six years (1991-1996) have been studied where there is deficit and excess rainy season. The aim of this study is also to deteminate the 'ground truth' over an area of 1 degree square (about 12 000 km^2) at a time scale of ten days and to propose abacus of rainfall error estimation according to the number of raingauges.

INFLUENCE OF SST ON OBSERVED MIDLATITUDE BLOCKING VARIABILITY

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In the context of the analysis of atmosphere low frequency variability and its modelling (particularly of blocking simulation produced in GCMs), a good performance of the model ECHAM4 T106 (10 years integration) has been found, mainly in the Euro-Atlantic sector . This integration, characterised by observed sea surface temperatures as the only external forcing, reproduces a blocking frequency time variability which matches surprisingly well the real one (reanalysis from 1 January 1979 up to 31 December 1988). In order to understand if these similarities are the product of chance or not, a Montecarlo simulation has been developed using a set of 1000 "alternative analyses" randomly generated from the real blocking frequency dataset (analysis from 1 March 1974 up to 28 February 1994, limited to 90°W-90E area). Observing the distribution of the correlation coefficients (calculated between each of the random maps and the model output), it has been found that the model output is correlated with the observed data with a value located 1.5 standard deviations right of the mean.

MAINTENANCE OF THE AFRICAN EASTERLY JET

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The maintenance of the African easterly jet (AEJ) has been examined using a zonally symmetric GCM with simple parametrizations. It is shown that the AEJ is maintained in association with two diabatically forced meridional circulations; one associated with surface fluxes and dry convection in the Saharan heat low region and one associated with deep moist convection in the ITCZ region equatorward of this. The heat low heating, which reaches the height of the AEJ around 700mb, is particularly important in maintaining the AEJ and its associated meridional gradients in potential vorticity. It is concluded that the mean observed AEJ results from a combination of the diabatically forced meridional circulations which maintain it and easterly waves which weaken it.

NUMERICAL STUDY OF THE IMPACT OF ENSO AND DECADAL SCALE SST VARIABILITY ON SAHEL RAINFALL

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Sahelian rainfall is strongly dependent on surface conditions and SST play a key role at interannual time-scales. However ENSO phenomenon is seldom put forward to explain rainfall variability in the Sahel. As a matter of fact the statistical relationship is weak but mainly due to its unstability through time and seems to depend on the global SST context - a decadal or longer time-scale variability. Numerical experiments performed with an AGCM help to investigate changes in the relationship between ENSO related conditions and Sahelian rainfall relatively to the prevailing global context. Recent ENSO events occuring in warmer southern ocean context have clear impact on the Sahelian rainfall in consistency with observations.

ROLES OF CUMULUS CONVECTION IN THE ATLANTIC EASTERLY WAVES

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Easterly waves are westward traveling tropospheric disturbances in the Tropics. They arise through a mixed barotropic/baroclinic instability of the low-level easterly jet. The importance of diabatic processes in the wave dynamics and energetics has yet been fully understood, due to poor representations of moist processes. A wave-CISK parameterization is often used in theoretical studies. To improve the representation of cumulus convection, one must first understand the role of mesoscale processes in the mass, heat and moisture budgets of the easterly waves, in addition to that of convective-scale processes. The main purpose of this study is to investigate these budgets and individual budget components for every phase of a composite easterly wave.

In this study, the UCLA/CSU cloud ensemble model (CEM) is used to explicitly simulate the macroscopic behavior of cumulus convection and its mesoscale organization during Phase III of the Global Atmospheric Research Program's (GARP's) Atlantic Tropical Experiment (GATE). Observed large-scale vertical motion and horizontal advections of temperature and moisture are used to drive the CEM for the entire Phase III. The simulations have been presented in Xu and Randall (1996). The observed easterly waves during Phase III were characterized as fully mature and strongly nonlinear. Only a composite easterly wave is studied with the simulated data. Compositing of data is accomplished by assigning each 3-hourly averaged variable to one of eight wave categories as in observational studies. Partitioning of convective and mesoscale stratiform regions is based upon the strength of updrafts/downdrafts (Xu 1995).

Implications for cumulus parameterization will also be discussed, based upon the results presented in this study.

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West Africa is an ecologically fragile area, with a low and extremely variable rainfall. A biosphere model, SSiB, was coupled with the COLA GCM to investigate the impact and mechanisms of land surface processes on seasonal and decadal variations of Sahal rainfall. The model was integrated for four years with and without vegetation cover degradation over the Sahel region. It has been found that the West African monsoon and African easterly jet are both sensitive to land surface processes. Changes in the annual cycle of Sahel rainfall in the degradation cases are consistent with observed climate anomalies of the past forty years. The condition of the land surface in West Africa has the largest impact compared with other sub-areas in the Sahel region. The monsoon flow from the Atlantic Ocean, then the moisture flux convergence, became weaker in the degradation cases. In contrast to the conventional hypothesis about albedo effects, it has been found that variations in the convective heating rate, which are caused by changes in latent-heat flux from the land surface and moisture flux convergence in the atmosphere, are the dominating factors in this process. Radiative cooling is a secondary effect. A preliminary study was also conducted to compare the effects of the land and SSTs.

OA17 Climate variability: models and observations (joint with SE)

02 Natural climate variability on the basis of past observations

Convener: Duplessy, J.-C.

CHANGES IN BAROCLINICITY AND SYNOPTIC ACTIVITY ON THE NORTHERN HEMISPHERE FROM THE 1960s TO THE PRESENT AS SEEN BY DISTINCT DATA SETS

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The large number of deep cyclones over the North Atlantic / European area during the first years of the 1990s led to the supposition, that the meridional temperature gradient of the troposphere has strengthened within the preceding decades. In this study northern hemispheric tropospheric temperatures and synoptic activity - in terms of baroclinicity and the interdiurnal variability of geopotential heights - are examined. It is found that the lower tropospheric temperature gradients as well as the synoptic activity increased during that period over the cyclogenetic centres over Newfoundland and over the Northwest Pacific, leading to an enforcing of meridional heat exchange processes due to synoptic eddies. But over continental areas (Asia/Siberia) the tropospheric warming within the midlatitudes caused a decrease of the meridional temperature contrast between lower latitudes and polar regions. This result can be obtained from three largely independent data sets: namely analysis data of the German Weather Service (DWD), the *Comprehensive Ocean-Atmospheric Data Set* (COADS) and the NCEP/NCAR Reanalysis data. The close connection between monthly mean baroclinicity - in terms of Bjerknes' solenoidal term - and the synoptic activity, obtained from daily observations, is another instructive result of the study.

GMSLP3: A GLOBAL MEAN SEA LEVEL PRESSURE DATASET.

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A global, observed, monthly, historical MSL pressure dataset (GMSLP3) has been developed to facilitate the validation of climate model results and the interpretation of observed global and regional climate variations. The dataset is composed of gridded values on a 5° resolution, dating back to 1871.

GMSLP3 is based on monthly mean land station data together with gridded ships measurements, which were subjected to a rigorous quality-control. These data, combined with data extracted from the National Centers for Environmental Prediction Reanalysis, were used to 'reconstruct' monthly gridded fields of MSL pressure using the 'Reduced Space Optimum Interpolation' technique developed by Alexey Kaplan of Lamont-Doherty Earth Observatory, Columbia University.

I will present an overview of the creation of GMSLP3, together with a brief discussion of its main features and improvements over previous versions of the dataset. I will also describe possible future avenues for development, including the creation of regional datasets for areas, such as Europe, where there are sufficient numbers of high quality observed data.

A GCM SIMULATION OF THE ^{14}C DISTRIBUTION IN THE GLACIAL OCEAN

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Natural radiocarbon (^{14}C) concentration is often used to assess the ventilation rate of the deep-water masses. At the Last Glacial Maximum (LGM), the ^{14}C concentration measured in sediments supports the idea of a different World Ocean circulation compared to present day, but due to the measurement uncertainties and the scarceness of reliable ^{14}C data, until now, a comprehensive ventilation sketch cannot be drawn. Here we investigate this question with a 3-D global OGCM that includes a radioactive decaying ^{14}C tracer, with a wind speed and sea-ice cover dependent surface exchange coefficient, but ignoring the complex biological carbon cycle. Two experiments under restoring boundary conditions are conducted, a reference run with present day forcing and a LGM simulation using CLIMAP SST and *Duplessy et al.* (1991) SSS reconstructions. The ^{14}C equilibrium distributions from the two experiments are presented. The modern ^{14}C is in good agreement with observations and offers a model validation as well as a reference state. The LGM ^{14}C distribution is compared with the few available reconstructions. The comparison with the modern simulation provides a clear view of the circulation changes, changes that are consistent with those inferred from proxies.

RAPID CLIMATIC EVENTS AND ASIAN MONSOON INTENSITY: MAGNETIC AND GEOCHEMICAL RESULTS FROM THE BAY OF BENGAL AND THE ANDAMAN SEA

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Results from high resolution study of magnetic mineralogy combined with major element geochemistry analysis, oxygen isotopes and ^{14}C AMS stratigraphy are reported for cores MD77-169 and MD77-180 located in the Andaman Sea and the Bay of Bengal respectively. In both cores the main magnetic mineral is PSD titanomagnetite with slight variations in grain size following orbital periodicities at 23 kyr and 100 kyr. The 23 kyr periodicity indicates that the variations of magnetic grain sizes are strongly influenced by the monsoon with relatively fine magnetic grains during periods of strong summer monsoon.
In core MD77-180, located at the mouth of the Ganges river, short term variations in magnetic grain sizes and in the chemical index alteration (CIA) are coeval during the last glacial period with the rapid variations observed in the $\delta^{18}O$ record of GISP2 ice core. The interstadials are characterized by fine magnetic grains and high CIA values. On the contrary, the cold Heinrich events correspond in core MD77-180 to intervals of relatively coarse grains and low CIA illustrating a decrease of the intensity of chemical weathering related to significantly drier conditions on the continent. We suggest that rapid cold events in North Atlantic during the last glacial stages are related to a weaker summer monsoon rainfall over the Himalaya via atmospheric teleconnection.

FLUCTUATIONS IN NORTH ATLANTIC HURRICANE FREQUENCY

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The annual record of hurricane activity in the North Atlantic from 1886–1996 is examined using time-series analysis. Singular spectrum analysis (SSA) combined with the maximum entropy method (MEM) is applied to the time-series of annual hurricane occurrences to extract the dominant modes of oscillation. The annual frequency of hurricanes is modulated on the biennial, semi-decadal, and near-decadal time scales. The biennial and semi-decadal oscillations correspond to two well-known physical forcings in the local and global climate. These are the shift in tropical stratospheric winds between an east and west phase (QBO), and a shift in equatorial Pacific Ocean temperatures between a warm and cold phase (ENSO). These climate signals have previously been implicated in modulating Atlantic hurricane activity on the inter-annual time scale. The near-decadal oscillation is a new finding. Separate analyses on tropical-only (TO) and baroclinically-enhanced (BE) hurricane frequencies show that the two components are largely complementary with respect to their frequency spectra. The spectrum of TO hurricanes is dominated by the timescales associated with ENSO and the QBO, while the near-decadal timescale dominates the spectrum of BE hurricanes. Speculations as to the cause of the near-decadal oscillation of BE hurricanes center on changes in Atlantic SSTs possibly through changes in evaporation rates, perhaps as a result of changes in solar activity.

WINTER PRECIPITATION IN PORTUGAL: TRENDS AND VARIABILITY USING A LINEAR MODEL BASED ON WEATHER TYPES

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Regime of precipitation in Portugal presents a highly seasonal character, with a broad winter peak and an almost complete lack of rain in summer. Based on an objective classification of Weather Types (WT's) developed for the UK (Jenkinson and Collison, 1972) and adapted for the present purpose, daily values of SLP were used to define 10 different WT's according to vorticity and prevailing direction of geostrophic wind flow. In a previous work, statistically significant relationships were found between monthly values of precipitation and monthly frequencies (number of days) of relevant WT's, *i.e.* Cyclonic (C), Southwestern (SW) and Western (W) types. In the present work monthly frequencies of these three relevant CWT's covering the winter period 1946-90 were used to predict monthly mean values of precipitation at 18 stations over Portugal. Multiple regression models were therefore developed for each station using three most relevant WT's as predictors. Each model was calibrated using winter months and then validated against March observations, all models revealed a good capacity in reproducing the temporal variability of March precipitation, especially the conspicuous decline that has been observed since the 60's. Although the models present similar values of explained variance over the country (≈80%), relative importance of each WT is distinct from station to station, a strong decrease (increase) being observed in importance of C (W) type from South to the North. Obtained results put into evidence the different mechanisms of precipitation in Portugal, orographic and cyclogenic activity being relevant respectively in the North and South of Portugal.

CLIMATE VARIABILITY IN ORENSE (SPAIN) IN THE LAST 300 YEARS

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Orense is an Spanish town placed in the Northwest of the Iberian Peninsula. Its meteorological station register data only since 1950, although Orense has the particularity of having an extremely ammount of historic documents with references to the weather of the town. The objective of this study is to reproduce two climatic variables (temperature and precipitation) for the last three centuries by means of historical sources and to analyze the climate variability. The great density of data permit us to know natural variability of climate in a single point

PLIOCENE WARMTH IN MEDITERRANEAN AREAS: RECONSTRUCTION FROM POLLEN DATA

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The Pliocene was the last time where there is good evidence that climate was significantly warmer than the present time. So, it is important to quantify this last warming-up. Climatic reconstructions from Pliocene pollen data cannot be based on modern analogue methods, as Pliocene pollen spectra contain mixture of taxa that do not grow together today. A new method that uses a climatic amplitude method has been carried out especially for the Pliocene. It relies on climatic ranges tolerated by plants. The climatic requirements of the main taxa represented in the pollen spectra have been defined on the basis of 8000 modern pollen spectra. The method have been applied to several Pliocene pollen sequences of the Mediterranean area. Both temperatures and precipitations were higher than the modern ones, especially at the northern latitudes. Our results are comparable with sea surface temperatures and with $\delta^{18}O$ variations obtained for the same period.

GLACIAL ATLANTIC SURFACE TEMPERATURES BASED ON NEW DATA AND A SEMI-INVERSE OCEAN MODEL

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A "SIMPLE ocean" model has been developed, which estimates surface currents in a diagnostic manner from surface winds. Horizontal heat transports by advection and diffusion and surface heat fluxes are used to calculated sea surface temperatures (SSTs). The unknown transports from the deep ocean are inversely calculated from sparse SST data. The model can be understood as a method to estimate a global SST field from a sparse data set, where it takes into account the wind driven surface currents.
In a control run for the modern ocean, SST data from the core top samples of about 200 CLIMAP sedimentary cores were used. The resultant global annual mean SST field matches the observations with a root mean square error of 1.85°C. A glacial run based on the glacial CLIMAP SSTs at the core sites already exhibited considerable deviations from the CLIMAP 2° × 2° interpolation in regions where no data existed.
For a second glacial run, new Atlantic core data provided by the Sonderforschungsbereich 313 in Kiel and the Sonderforschungsbereich 261 in Bremen have been used. The complete SST field estimated with the SIMPLE ocean model is presented and compared with the CLIMAP reconstruction.

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The phenomenon of dependence of precipitation amounts on the lunar phase (synodical month) has been studied since the 1960s in details by numerous authors in many countries, e. g. in Australia, Czechoslovakia, Italy and especially thoroughly in the USA. Data from thousands stations covering period of more than 50 years were subjected to rigorous tests with conclusion that the association of lunar phases with heavy rainfall is real. The statistical method applied in these works had often been a modification of method of superposition of epochs (MSE). The results proved that extreme precipitation events vary nearly simultaneously over all regions of the Earth and that they occur more frequently on the third to fifth day after syzygies. The concurrence and angular uniformity of the phenomenon have been questioned during last few years a that is base for this attempt to study statistical characteristics of results of MSE applied on a very long precipitation series of Prague-Klementinum (1805-1996). Despite largely shared belief of two-extremal course of mean precipitation during synodical month this study indicates that this is rather exceptional and that there are quasi-linear shifts on the curves of synodical signal with time scale of tens of years, not comparable with basic periods of lunar orbit.

THE FINE STRUCTURE OF THE SPECTRAL MAXIMA OF VARIATIONS OF SEA LEVEL,AIR PRESSURE AND AIR TEMPERATURE FOR PERIODS FROMSEVERAL DAYS TO SEVERAL MONTHS.

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The several broad maxima of spectrum of variations of sea level, air pressure and air temperature are existed inside the diapazone of periods from several days to several months. The periods corresponded to maximal values are located near to the same position for spectra of the air pressure, air temperature and sea level, which are recorded in the different points. The main maxima are located near to the period 15 days, 30 days , 45 days. We have analyzed the dependence of the form and positions of the spectral line on duration of the sample for case of the sample durations from 1 to 40 years in case of the points Holmsk (47.0 N,142.0 E) and Terney (45.1 N, 136.5 E) in time interval from 1950 to 1990. These maximal values are discovered for different samples if the sample duration is less than 1 year. For case of the sample duration more than 2 year the maxima are split for several separate maxima. If we increase the sample duration, the positions of the separate maxima do not change essential , but the widths of maxima get smaller and the heights of maxima increases. If the sample duration is more than 8 year this is the line spectrum . Instead of several maxima we have received the several groups of lines, strips. Each strip contains several lines. The distances between the lines of the separate strip are near to the the same and near to the value 2 pi / 365 1/day. The most essential lines of the second strip correspond to periods 27.3 and 29.5 days. These are the periods of the rotation of the Moon.

NORTH-ATLANTIC-EUROPEAN ATMOSPHERIC CIRCULATION CHANGES BETWEEN THE EARLY INSTRUMENTAL PERIOD AND THE RECENT CENTURY

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Within the EU-Project ADVICE ("Annual to Decadal Variability in Climate in Europe") changes of climate and atmospheric circulation since 1780 are investigated on the basis of early instrumental observations. Using monthly mean SLP grids for the North-Atlantic-European region reconstructed back to 1780 by Jones et al. (CRU 1997) an objective classification has been developped based on EOF and cluster analyses. Comparing the early instrumental period (1780-1860) with the recent century, changes in frequency and seasonal distribution are revealed for some of the resulting circulation patterns. Furthermore, some 72 temperature and 62 precipitation series, respectively, from Central Europe are used to select warm, cold, wet and dry months since 1780. SLP grids from these months are submitted to T-mode principal component analyses in order to derive basic circulation patterns associated with these climate anomalies. Comparing explained variances between the early instrumental period and the recent century gives indications about climate-related atmospheric circulation changes.

COMPARISON ANALYSIS OF SECULAR VARIATIONS OF SOLAR, GEOMAGNETIC AND METEOROLOGICAL PARAMETERS

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Long series of sunspot numbers and indices of geomagnetic activity from 1868 to 1990 have been examined by the method of cross-correlation analysis. Secular variations of the 23-year running correlation between the sunspot numbers and the parameters of geomagnetic activity with a characteristic period of about 50 years have been obtained. The selected secular variations of solar-geomagnetic coupling have been compared with long-term variations of two solar indices that are potential proxy measures for the solar irradiance: the length of the sunspot cycle and the Hoyt & Schatten's composite index. It has been shown that fluctuations of these indices relative to their linear trend change their sign in accordance with the secular variations of the solar-geomagnetic coupling. Long-term fluctuations of the Earth global land-air surface temperature anomalies relative to their linear trend have a period of about 50 years and show a good agreement with the secular variations of the solar-geomagnetic coupling.

RAPID CLIMATIC VARIATIONS AND MAGNETIC MINERALOGY CHANGES IN NORTH ATLANTIC SEDIMENTS.

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High resolution magnetic analyses of four cores located in the northern part of North Atlantic are presented. The cores are disctributed along an E-W transect between 60 and 62°N from the Faeroe islands (cores ENAM 93-21 and core MD95-2009), the Gardar drift (core SU90-33) and the Irminger basin (core SU90-24). The study has been focussed on climatic stage 3 during which variations in the low field magnetic susceptibility are correlated with temperature changes over Greenland as observed from the ice cores.

Changes in low field magnetic susceptibility illustrate variations in both concentration and grain sizes of magnetites and Ti-magnetites. The Heinrich events are characterized by low concentration of relatively fine grained magnetic particles. On the contrary, during interstadials 3 to 13 (Dansgaard-Oeschger events) high concentrations of relatively coarse magnetic grains are observed. The results of a high resolution (2 to 10 cm intervals) study of magnetic hysteresis parameters will be also reported and discussed

The possible origin for these variations in the magnetic properties of the sediment will be discussed in the known climatic framework of this region.

CHANGES IN THE STRENGTH OF THE ICELAND-SCOTLAND OVERFLOW WATER IN THE LAST 200,000 YEARS: EVIDENCE FROM MAGNETIC ANISOTROPY ANALYSIS OF CORE SU90-33

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The anisotropy of magnetic susceptibility combined with mineral magnetic analysis is used as paleo-bottom current indicator. The degree of anisotropy illustrates the degree of preferential alignement of elongated magnetic particles, in turn related to the strength of the bottom current. Results are reported for core SU90-33 located (60°34'4N, 22°05'1W) at 2400m water depth along the Iceland-Scotland overflow water (ISOW). This core spans the last 6 climatic stages. The main magnetic mineral is low Ti-content magnetite with very slight downcore changes in the grain size. Both the susceptibility record and the changes of the proportion of smectite in the clay fraction are climatically controlled with lower values during glacial than during interglacial periods. The degree of anisotropy is significantly larger during interglacial periods than during glacial times. These changes provide evidence that the strength of the contour current associated to the transport of the ISOW appears to have been significantly larger during climatic stages 5, 3 and 1 than during stages 6, 4 and 2. Measurements in modern North Atlantic sediments will be also presented.

SEA SURFACE SALINITY RECONSTRUCTION OF THE INDIAN OCEAN DURING THE LAST GLACIAL MAXIMUM (ABOUT 18,000 YR B.P.)

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The oxygen isotope composition of planktonic foraminiferal tests includes contributions from sea surface temperature, global ice volume and local salinity. To reconstruct surface water salinity in the Indian Ocean at the last glacial maximum (about 18,000 yr B.P.) we have used the method developped by Duplessy et al., 1991. This method is based on a comparison between transfer function estimates of sea surface temperature and the oxygen isotope ratio of planktonic foraminiferal tests. For our study we have used a common planktonic foraminiferal species in the Indian Ocean, *G. ruber*. *G. ruber* is considered to live preferentially in the upper part of the euphotic zone (surface dweller) and to prefer warm conditions. We first used core-top analyses to demonstrate that, under modern conditions, the paleotemperatures determined from the isotopic composition of foraminiferal shells are linearly linked to the sea surface temperature of the warmer month. We then used this information to derive an estimate of the isotopic composition and salinity of the Indian Ocean surface water during the last glacial maximum. For the transfert function we have used ice age sea surface temperatures reconstructed by CLIMAP (1981). This sea surface salinity estimation enables us to reconstruct changes in the Indian Ocean monsoon and changes in sea surface circulation at the last glacial maximum in the Indian Ocean.

DYNAMICALLY CHARACTERISTIC OF THE ATMOSPHERE PARAMETERS DURING INTENSIVE MAGNETIC STORMS

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It is well known that Solar activity has a great influence to the upper atmosphere features. The alternation of corpuscular radiation strength, causes great changes of atmospheric parameters. The correlation between dynamically characteristic of the atmospheric parameters (air pressure, air temperature, humidity and quantity of falls) and variation of geomagnetic activity is presented. In this paper, authors established the correlation between average daily air temperature and index of geomagnetic activity (K) in time of intensive geomagnetic storms. That correlation is observed in the course of hours at days when magnetic storms are detected in Belgrade area. Solar geomagnetic activity and temperature changes could be observed like external factors of increase number of calling from individual groups of diseases. In this paper, dynamical characteristic number of calling from KV diseases, psychosis, cancer of the lungs, in the time of intensive magnetic storms registrations, when big changes of air temperature have been registered in Belgrade.

STUDY OF PERSISTENCE OF SSTA FROM ATLANTIC OCEAN BY MEANS OF MARKOV MODEL

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Monthly values of SSTA (Sea Surface Temperature Anomalies), defined in 522 points in the Atlantic Ocean (75^0W-10^0E,70^0N - 70^0S) in the period 1948-1994, have been analysed. The autocorrelation function which approximates the signal series is assumed that satisfies a Markovian process under the form C exp(- A|k|). In order to estimate C and A, the autocorrelation function was truncated until a lag where it becomes negative. In the paper, for each point, the decreasing rate (A), signal level (C), the effective time (T_0) and signal -to-noise ratio are presented and discussed. Concerning the T_0 values, which estimate the persistence level, in the Northern Hemisphere the values between 5 and 7 months are dominant, except for some areas situated between equator and 10^0 N, as well as around the latitude of 30^0 N ,where the persistence is lower than 5 months, while in the regions (45^0N - 60^0N ; 45^0W - 20^0W) and (10^0N - 20^0N ; 70^0W-50^0W), the memory of SST anomalies is within the interval of 7 to 9 months with isolated points which have even 11 months.

CLIMATIC CHANGES IN THE LAST MILLENNIUM

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When the glacial eustatic sea level rise finished in Mid-Holocene time, a long-term deceleration in the Earth's rate of rotation ended, and, by that, the Earth came into a new dynamic mode where the feed-back interchange of angular momentum between the solid Earth and the hydrosphere got a dominant role for the distribution of heat (recorded in the regional paleoclimatic changes) and mass (recorded in the regional sea level changes) due to its effects on the ocean circulation. At around 800-1000 AD, the Earth's rate of rotation changed. This initiated - as the beating on a cord - a sequences changes between "Super-non-ENSO" condi-tions (around 950 AD), "Super-ENSO" conditions (around 1100 AD) and a second period of "Super-non-ENSO" conditions (responsible for the so-called Medieval Warm Optimum around 1250 AD). The cold periods in 1440-1460, 1687-1703 and 1808-1821 (or "Little Ice Ages") in relation to the Spörer, Maunder and Dalton sunsput minima seem all to represent similar oceanographic circulation changes in the North Atlantic and not any decrease in solar irradiance.

AFRICAN AND ASIAN MONSOON CHANGES AT 6000 BP INFERRED FROM A FULL COUPLED OCEAN-ATMOSPHERE MODEL.

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African and Asian monsoons were enhanced at 6 ka BP in response to an increased summer insolation. Simulations of the Paleoclimate Modeling Intercomparison Project (PMIP) reproduce this increase, but the northward extend of monsoon rain suggested by lakes and pollen data in North Africa is underestimated. PMIP simulations have been performed using atmospheric models with present day surface conditions. Part of the mismatch could therefore be attributed to the neglected feedbacks from ocean and vegetation.
Here, we investigate the role of the ocean in the 6 ka BP climate change using the IPSL (Paris, France) coupled ocean-atmosphere model with no flux correction at the air-sea interface. For the 6 ka BP simulation, only the orbital parameters have been changed and set to those of 6 ka BP, compared to the coupled control simulation.
The change in sea surface seasonal cycle helps to further enhanced the monsoon in Africa and Asia compared to simulations with the atmospheric model only forced by PMIP type surface conditions. Over Africa the coupling introduces a northward shift of the ITCZ over the continents which however is not sufficient to match the data.
The changes of meridional heat transport are opposite in the two fluids, the oceanic changes being larger except during the peak of the summer monsoon. In the Atlantic, the northward oceanic heat transport across the equator vanishes at 6 ka BP, but is relaved bv the transport by the monsoon winds.

1997 TEMPERATURES ARE HIGHEST ON RECORD: SHOULD IT BE ATTRIBUTED TO THE GLOBAL WARMING?

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Globally-averaged surface air temperature for 1997 appears to be the highest on record. This should not be necessarily attributed to the global warming, since in 1997 two (seemingly unrelated) positive temperature anomalies occurred: (1) a very large positive February-March anomaly over continental band 55-65 °N, apparently resulting from strong westerlies in the N. Atlantic and N. Pacific, and (2) the El Niño phase of the Southern Oscillation. From our calculations these two events contributed a substantial fraction of the global 1997 yearly anomaly.

DANSGAARD-OESCHGER OSCILLATIONS: A HYDRODYNAMIC THEORY

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The millennium timescale climate variability that is so clearly evident through Oxygen Isotope Stage 3 of the last glacial cycle has come to be referred to as consisting of distinct Dansgaard-Oeschger oscillations. These appear in the oxygen isotopic time series derived from Summit Greenland ice cores as bundles which appear to define a "Bond cycle" whose characteristic period is approximately 10 kyr and which appear to be initiated by individual "Heinrich events". We have developed a series of models which explore the extent to which the D-O oscillation may be understood to be a natural mode of internal variability of the thermohaline circulation of the Atlantic ocean that exists under glacial boundary conditions. As we have shown (Sakai and Peltier, 1997, J. Clim.) our model of the THC actually "fibrillates" in response to the anomalous P-E forcing that is required to reduce the high latitude salinity to the low values that are known to characterize the glacial state. More recently this same Hopf bifurcation mediated transition has been shown to occur in a simple box model which is a modest extension of that originally introduced by Stommel. With the latter model it has also proven possible to acceptably mimic the Bond cycle by modulating the applied P-E anomaly in the way suggested by the repetitive nature of the Heinrich events.

CLIMATIC RECONSTRUCTION IN EAST AFRICA FOR 6,000 YR B.P. FROM POLLEN DATA

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Comparisons of reconstructed paleoclimates from proxy-data with AGCM simulations provide a way to evaluate mechanisms of climate changes and to test how well models simulate the climates of the past. The 6ka time slice is a major focus of the paleoclimate modelling community. Africa is a key region to study changes in monsoon strength and extension through time. To provide quantitative and spatial estimations of the 6 ka climate in East Africa, we used three different methods : (1) the classic best analogues method ; (2) the best analogues method with a lake-level constraint ; (3) the plant functional type method based on a combination of pollen types grouped according to plant ecology.
A modern pollen dataset including 450 samples and a dataset of 33 pollen samples for 6 ka were used. The bioclimatic parameters reconstructed are the moisture index and the annual precipitation amount. Results shows an East Africa climate globally wetter at 6ka than today. This feature is consistent with the lake-levels which were higher than at present. Results are spatially consistent but the reconstructed climate for the sites located at very high elevation is less good.

INTERDECADAL CLIMATE VARIABILITY OVER THE NORTHERN BLACK SEA COAST ASSOCIATED WITH THE CHANGES IN THE COUPLED OCEAN-ATMOSPHERE SYSTEM

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The aim of the talk is to discuss the low-frequencychanges of the hydrometeorological and hydrographicparameters overthe coastal zoneof theNorthernBlackSeageneratedby the global changes in thecoupled ocean-atmosphere sytem. Regional archive ofthe Marine Hydrophysical Institute for 1950 to 1994was used for the analysis of high-amplitude decadaltointerdecadalvariabilityoftemperatureandsalinity in the N.W.Black Sea.The typical magnitudeof the decadal changes of monthlySST/SSSin thissea region is of 1C/1.5psu. High-correlated decadal-scale changes of the sealevelpressure over theNorth Atlantic, of the air temperature and precipi-tation over the Crimea, and of theBlack Sea riverdischarges in 1906 to 1994 were examined using mon-thly and yearly historical data sets.Our recent andearlier results shown that the decadal-scale varia-bility in the coupled system over the North Atlant-ic Ocean is due mostlyto the inherent changesofthe oceanic meridional heat fluxes there. The asso-ciated changes of temperature.pressure and cyclonicactivity over the Central/EasternEurope cause theBlack Sea coastal changes.

GLOBAL AND REGIONAL OPTIMAL AVERAGES AND ASSOCIATED ERROR ESTIMATES OF ANNUAL OBSERVED SURFACE TEMPERATURE ANOMALY.

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Global and regional optimally averaged combined land air and sea surface temperature anomalies, with respect to 1961–90, are presented with their associated uncertainties. The optimum averaging procedure uses covariance EOFs of observed surface temperature anomalies, combined with data from the NOAA National Centers for Environmental Prediction Reanalysis over the poles, to specify their statistical structure. Input data were gridded annual 5° area Climatic Research Unit land air temperature and Meteorological Office Historical Sea Surface Temperature (MOHSST6) anomalies. The latter were first corrected before 1942 for changes in instrumentation with time. Estimates of the sampling uncertainty of each gridded anomaly, and the uncertainty of the instrumental corrections were input. The results are an average of the available annual data, combined according to their reliability and position with respect to the main modes of variability of the field, and an estimate of the possible error in this average allowing for all data-voids. Decadal average error estimates are calculated using annual errors. From this we can say that the decade 1988–1997 was significantly warmer than the decade 1978–1987 and all previous decades back to the 1860s.

COMBINED DYNAMICAL AND STATISTICAL MODELLING FOR THE INTERPRETATION OF IN SITU PALEO RECORDS

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Recent proxy data obtained from ice-core measurements, dendrochronology and valley glaciers provide important information on the evolution of the regional or local climate. General Circulation Models integrated over a long period of time could help to understand the forcing mechanisms (external and internal) of natural climate variability. For a systematic interpretation of local paleo proxy-records, a combined method of dynamical and statistical modelling is proposed. It is anticipated to simulate local paleo records by first undertaking a model consistent statistical downscaling and then use a forward modelling approach to obtain the behaviour of valley glaciers and the growth of trees under specific conditions. The simulated records can be compared to actual proxy-records in order to investigate whether e.g. the response of glaciers to climatic change can be reproduced by models and to what extent climate variability obtained from proxy-records (last millenium) can be represented. For statistical downscaling, a multiple linear forward regression model is used with the assumption that local weather conditions can be determined by large scale flow patterns of the atmosphere. For any locally observed weather parameter, sets of large-scale predictors at various pressure levels are used. It is found that daily data are required due to strong dependence on individual synoptic scale patterns. For development of the model, daily values of ECMWF-Reanalysis data are used. The results of the statistical model are then applied to a long integration of an ECHAM4 / Mixed Layer Ocean experiment and a GCM simulating preindustrial climate variability.

THE ROLE OF THE INDONESIAN THROUGHFLOW IN EQUATORIAL PACIFIC THERMOCLINE VENTILATION

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The role of the Indonesian Throughflow (ITF) in the ventilation of the equatorial thermocline of the Pacific Ocean is explored using a primitive equation ocean circulation model. Model results for a model domain with an open Indonesian passage are compared with runs for a closed Pacific domain. Three cases are presented: a run with no throughflow, a run with 10 Sv of imposed ITF transport, and a run with 20 Sv of imposed ITF transport. For each case the model is forced at the sea surface with seasonally varying wind stress fields, and surface heat fluxes are calculated using an atmospheric boundary layer model. Two idealized tracers are advected online to distinguish between thermocline waters of northern and southern origin which ventilate the equatorial thermocline. There are two principle findings to this study; first, that the mixing ration of northern to southern component waters in the equatorial thermocline is highly sensitive to the ITF transport, and second, that the sea surface temperature in the eastern equatorial Pacific exhibits a strong sensitivity to the ITF transport. The implications for thermal budgets in the Pacific Ocean are discussed.

LATEGLACIAL AND HOLOCENE CLIMATIC HISTORY IN GREAT BRITAIN FROM LAND SNAIL ASSEMBLAGES.

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Here we present a high resolution record from a Lateglacial-Holocene land snail succession from S.E. England. Temperature estimates, derived from the best analogues technique, indicate a cooling trend, between 14,500 and 12,600 cal BP, of 4° in summer and 8° in winter to the Younger Dryas event. The strong warming following the Younger Dryas stadial corresponds to increasing values of the same magnitude in 600 years. A cooling event, weaker than the Younger Dryas, of 1° in both seasons is recorded between 8,000 and 8,500 cal BP. These reconstructions from an European Holocene continental sequence are in agreement with fluctuations already described in North Atlantic, Mediterranean, and ice cores and African and Tibetan lakes records.

MULTIFRACTAL "NATURAL CLIMATE VARIABILITY"

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In order to detect a possible anthropic influence on climate one needs an accurate modelling of "natural climate variability". This modelling is usually done with a Gaussian noise, used as input into climate models. With a carefull scaling analysis, using wavelets, we show that various climate data show multifractal statistics: they are scaling and intermittent, with extreme events much more frequent than would give a Gaussian noise. This indicates that Gaussian noise or random walk strongly underestimate the variability. The latters are additive processes whereas multifractals correspond to multiplicative processes, displaying long-range correlations.

In the framework of this more realistic modelling of natural climate variability, it is quite possible that the recent "proofs" of human influence on climate no longer hold.

18 KA BIOMES RECONSTRUCTED FROM POLLEN AND PLANT MACROFOSSIL DATA FROM NORTHERN EURASIA: PALAEOCLIMATIC INTERPRETATION

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Newly compiled pollen and plant macrofossil data from northern Eurasia were used to reconstruct vegetation of the last glacial maximum. That reconstruction was done with a quantitative method of biomization (Prentice *et al.*, 1996). At 18 ka tundra dominated a large area north of 57°N latitude at the place of modern cold deciduous and taiga forests. Cool steppe was reconstructed south of that latitude where cool mixed and temperate deciduous forests grow today. Taiga appeared northeast of the Black Sea, ca 1500 km south of its present limit in the European Russia, while in south-western Siberia taiga was reconstructed only slightly south of its southern limit today, suggesting the influence of the Scandinavian ice sheet was more pronounced west of the Urals. Broad-leaved trees were confined to the eastern coast of the Black Sea, where cool mixed and cool conifer forests reconstructed at 18 ka. The limited pollen data from central Asia and Mongolia do not provide evidences that vegetation was substantially differ from today. Reconstructed vegetation changes have been explained by the global cooling and change in the atmospheric circulation. Dry and cold north-easterly winds from the Scandinavian glacial anticyclone entered eastern Europe and southward shift of the westerly jet caused wetter conditions in southern Europe as far as western Georgia. These results are a contribution to the IGBP-PAGES sponsored Biome6000, PEPIII and PMIP projects.

AN ANALYSIS OF ITALIAN LONG TEMPERATURE AND PRECIPITATION TIME SERIES

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A preliminary analysis of a number of Italian temperature and daily rainfall long time series is offered. After a preliminary investigation of time series homogeneity, the investigation is carried out in order to detect trends, abrupt changes or frequency peaks, indicators of climate change. A discussion of results is offered in the frame of climate model simulation output.

VARIATIONS OF THE DEUTERIUM EXCESS OVER THE LAST CLIMATIC CYCLE IN THE VOSTOK ICE CORE

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Isotopic records measured along polar ice cores are currently used to reconstruct paleotemperatures. In order to obtain additional information on the water cycle, attention has been more recently paid to the deuterium excess (d), defined as the deviation from the meteoric water line : $d = \delta D - 8\delta^{18}O$. Simple isotopic models have shown the dependency of d to the characteristics of the moisture source (sea surface temperature, relative humidity, surface wind speed).

We have measured a continuous deuterium excess profile over the last climatic cycle back to 150 kyr along the Vostok ice core. The d fluctuations are interpreted in terms of changes in the moisture origins.

A strong anticorrelation between d and obliquity suggests a modulation of high latitudes moisture sources by changes in sea ice extent.

High values of d during cold stage 5d compared with lower d values during cold stages 2, 4 and 6 could be explained by the superimposition of two effects at stage 5d : less moisture from the high latitudes (a lower atmospheric circulation at high latitudes), and more moisture from the low latitudes (tropical ocean still warm during stage 5d).

SEASONALITY OF LOW-FREQUENCY VARIABILITY IN EARLY-INSTRUMENTAL TEMPERATURES

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Earlier analyses of instrumental data (e.g. Briffa and Jones, 1993) showed the existence of season-specific features of natural climate variability on timescales up to a few decades. It is often argued that on longer timescales variability is independent of seasonality. We have addressed this issue by analysing the 7 long early-instrumental temperature records available for Europe. Spatially coherent oscillations are identified by applying (Multichannel) Singular Spectrum Analysis. Analysing summer and winter records separately, we found that the patterns of low-frequency variability (timescales larger than 50 years) are clearly season-specific. This holds both with and without the inclusion of the industrial segment. Winter temperatures show a slow warming, which is synchronous at all locations. Summer temperatures exhibit a timescale of about 150 years with a complex spatial pattern. Variability on this timescale is masked in the annual-mean data, because fluctuations in summer and winter tend to cancel. This implies that, also on longer timescales, summer and winter temperature patterns are controlled by different mechanisms. Consequently, networks of paleo proxies, which are used for reconstructing low frequency variability patterns, have to be seasonally homogeneous. Joint analysis of seasonally homogeneous paleo and early-instrumental data sets shows consistent variability patterns.

SENSITIVITY OF THE ATMOSPHERIC GENERAL CIRCULATION MODEL ECHAM 3 TO DIFFERENT GLACIAL SEA SURFACE TEMPERATURES

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Model-data comparisons within the Paleoclimate Modelling Intercomparison Project (PMIP) exhibit disagreements between the model output and the proxy data in some regions. These disagreements may either be caused by model inaccuracies or by unproper boundary conditions used by PMIP.
Here, the sensitivity of the atmospheric general circulation model ECHAM 3 to different boundary conditions for the last glacial maximum is investigated. In a first experiment the model is forced by CLIMAP sea surface temperatures (SSTs) as agreed upon within PMIP. For a sensitivity study the CLIMAP SSTs in the North Atlantic are replaced by new reconstructions of Sarnthein et al. Compared with the results based on PMIP boundary conditions, the changes of the model response to modified SSTs are very local and quite strong. Changes of the atmospheric parameters like surface air temperature occur mainly over the North Atlantic and Eurasian continent. The results of this investigation suggest that uncertainties in SST are important and may account for some of the model-data disagreements.

OA17 Climate variability: models and observations (joint with SE)

03 Climate variability: time scale interactions

Convener: Slingo, J.M.

THE INTERACTION BETWEEN INTRASEASONAL AND INTERANNUAL VARIABILITY AND ITS RELEVANCE FOR THE SEASONAL PREDICTABILITY OF THE ASIAN SUMMER MONSOON.

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Using ECMWF and NCEP Reanalyses the dominant modes of interannual and intraseasonal variability have been identified. These show a common mode which describes the latitudinal displacement of the Tropical Convergence Zone from its oceanic to continental regime. On intraseasonal timescales this mode appears to describe the active/break cycles of the monsoon associated with northward propagating events. Using these results, the relationship between intraseasonal variability and seasonal mean anomalies has been investigated.

SENSITIVITY OF THE CLIMATE OF A GCM TO THE BOUNDARY LAYER PARAMETERIZATIONS

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The sensitivity of the Global AGCM [1] to the parameterization of vertical diffusion in the boundary layer has been studied. Two PBL packages (Helfand and Labraga [2] and Z.Janjic [3]) are being compared in climatic runs for the two years 1987 and 1988 with prescribed sea surface temperatures. The sensitivity of the model's angular momentum cycle and poleward transport of energy, which are climatically of great importance was the main subject of interest in this study. These and other model properties for the two vertical diffusion schemes are compared both in long-term (2 year) runs and short-term (4 month) ensemble integrations.

[1] J.R.Bates, S.Moorthi, and R.W.Higgins, 1993: A global multilevel atmospheric model using a vector semi-lagrangian finite-difference scheme. Part I: adiabatic formulation. Mon. Wea. Rev., Vol.121, 244-263.

[2] Helfand, H.M., and J.C.Labraga, 1988: Design of a non-singular level 2.5 second order closure model for the prediction of atmospheric turbulence. J. Atmos. Sci., 45, 113-132.

[3] Janjic, Z.I., 1994: The step-mountain coordinate model: further development of the convection, viscous sublayer, and turbulence closure schemes. Mon. Wea. Rev., Vol.122, No.5, 927-945.

IMPACT OF SST FORCING ON THE MONSOONS OF 1987/88

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The interaction between ENSO and the monsoon was pronounced during the MONEG years 1987/88. Some of the AMIP simulations carried out with ECHAM captured the difference between the poor and the good Indian monsoon in these two years. The importance of the SST is investigated by rerunning the model without SST anomalies for different starting dates in early to late spring. Results for Indian rainfall and upper level velocity potential will be shown, and the importance of the SST forcing compared to impacts from, e.g. the land surface discussed.

SIMULATION OF INTERDECADAL HEAT STORAGES AND HEAT BUDGETS IN THE UPPER 400 m OF THE PACIFIC OCEAN

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We use a primitive equation isopycnal model of the Pacific Ocean to simulate and diagnose the anomalous heat balance on interdecadal timescales associated with heat storage changes observed from 1970-88 in the XBT dataset. Given the smallness of the interdecadal signals compared to the dominant ENSO signal, the agreement between model and observations is remarkably good and encourages future studies aiming to shed light on the poorly understood interdecadal timescale.
The interdecadal total (diabatic plus adiabatic) heat balance in the North Pacific Ocean is characterized by a complicated interplay of different physical processes, especially revealed in basin-scale averages of the the heat budget components which have comparable amounts of variance.
The diabatic heat balance north of 24°N, can be simplified to a balance between the tendency term, surface heat flux and meridional advection, the latter term dominated by anomalous advection of mean temperature gradients.
An important finding is the identification of two interdecadal timescales, roughly 10 y and 20 y, both similar to those reported by other investigators. The 20-y timescale is only present in diabatic heat budget components, while the 10-y timescale is present in both diabatic and adiabatic components. The role of the atmospheric forcing by surface heat flux is far more important for interdecadal timescales than for ENSO timescales.

A DYNAMICAL STABILIZER IN THE CLIMATE SYSTEM: A MECHANISM SUGGESTED BY A SIMPLE MODEL

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A fundamental question in climate research is that of how climate stability is maintained. A simple conceptual atmosphere-ocean model using parameterizations derived from observations has been developed which indicates that there may be a dynamical mechanism based on the poleward angular momentum transport (AMT) contributing to climate stability. A study of the observed seasonal variation of AMT across 30° N shows that it can be parameterized in terms of tropical-extratropical 500hPa height differences. The AMT is used to determine the surface winds and evaporation in the model. Infrared energy loss from the surface is parameterized in a way that includes the positive water vapour feedback. Analytical solutions are obtained which show that the dynamical feedback due to the AMT counteracts the water vapour feedback and holds the model climate stable.

DO WESTERLY WIND BURSTS LIMIT ENSO PREDICTABILITY?

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A conceptual model for ENSO is that of the Delayed Oscillator, according to which ENSO would consist in a redistribution of energy in the upper ocean with a timescale determined by ocean wave dynamics. Under this scenario, the tropical atmosphere would play a passive role, acting as a "slave" of the ocean. Several models that showed significant skill in ENSO predictions were based on these hypothesis.

Thanks to the great improvement of the observing system over the last decade it has been possible to monitor the development of a large El Nino event right from the beginning. The occurrence of strong westerly wind burst preceding (or triggering?) the onset of the 96/97 El Nino suggests that the high frequency variability of the atmosphere may play a more important role in ENSO than previously thought. This fact may have relevant consequences for seasonal predictability. The development of the 96/97 El Nino as analyzed and forecast by the ECMWF will be presented, and the role of the westerly wind bursts discussed.

INTRASEASONAL KELVIN WAVES IN THE TROPICAL PACIFIC

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Equatorial Kelvin waves are a prominent component of the intraseasonal variability in the tropical Pacific. While the linear theory of these waves has long been known many aspects of their behaviour, for example their relationship to ENSO, remain poorly understood. In recent years the development of the TAO array and the availability of accurate altimetry have greatly increased our knowledge of intraseasonal Kelvin waves. The use of this data in conjunction with numerical models offers an unprecedented opportunity for detailed study of these waves.
We have investigated the effect of ENSO on intraseasonal Kelvin waves with an OGCM forced with realistic surface fluxes. La Niña conditions reduce the west-east Kelvin wave transmission and Kelvin waves are slower during the cold ENSO phase. The intraseasonal Kelvin waves are more strongly damped during La Niña, due to increased viscosity, (resolved) eddy energy transport by Tropical Instability waves, and downward energy propagation. Partial reflection off the west-east sloping thermocline may also account for some reduction of the Kelvin wave amplitudes in the eastern Pacific. There is no evidence for wave breaking, or energy transfer between the baroclinic modes.

COMPARING SIGNALS OF ENSO AND NAO FOR SELECTED REGIONS OF THE NORTHERN HEMISPHERE

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It has been demonstrated that ENSO phenomenon influences many climatic variables of different regions of the Earth. The North Atlantic Oscillation (NAO) has also some climatic effects. However the accuracy of estimating statistically the climatic variables using directly indices of Southern Oscillation and NAO indices are, limited due to, among others, the autocorrelation and multi-correlinearity among these variables. The main idea of the paper is to develop a relationship between those indices and large-scale patterns of atmospheric circulation over the area examined. Then an analysis of atmospheric circulation patterns (CPs) is used to explain the linkage between large-scale forcing and local climatic response via a conditional probability framework. Given such a relationship the accuracy of estimating local climatic variables from ENSO can be expected to increase. First, the CPs will be defined and the CP time series will be described. Then, the time series of hemispherical large-scale circulation will be compared for the different oscillation events. The frequency distributions of time series of CP types under different phases were compared. Then, for the new systems some climate parameters were compared. This procedure was used for midlatitudes in the Northern Hemisphere (Atlantic European and Western U.S. region).

THE INFLUENCE OF MIDLATITUDE OCEAN/ATMOSPHERE COUPLING ON THE LOW-FREQUENCY VARIABILITY OF A GCM WITH TROPICAL SST FORCING

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In this study we investigate the impact of midlatitude ocean/atmosphere interactions on the atmospheric circulation and, in particular, on the extratropical response to ENSO-type forcing. Two GCM simulations with and without an interactive mixed-layer ocean in midlatitudes and with realistic SST variability in the tropical Pacific are performed. We find that midlatitude coupling alters the spatial organization of the atmospheric low-frequency variability in qualitatively the same manner (but not to the same extent) as tropical SST variability, namely by selectively enhancing certain of the pre-existing (natural) dominant modes without significantly modifying them or generating new ones. While tropical SST forcing results in a notable amplification of the PNA mode of the model, midlatitude coupling appears to favor the regional zonal index circulations in the eastern and western Pacific. As a result, coupling qualitatively modifies the structure of the extratropical response to ENSO-like tropical SST forcing by conferring Western-Pacific-like characteristics to this remotely forced signal, thereby improving its resemblance to the observed ENSO teleconnection pattern, while weakening its projection onto the PNA mode. Coupling also increases the persistence of the overall signal. The simulated covariability in the Pacific sector possesses the same kind of interannual/intraseasonal duality exhibited by the observations. This implies that two-way air/sea interactions and ocean dynamics may not play an essential role in determining the large-scale spatial structure of the observed dominant modes of covariability.

ON LONG EQUATORIAL WAVE REFLECTION

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Long equatorial wave reflection at the Pacific ocean boundaries are studied over the period October 1992-April 1997 using TOPEX/POSEIDON sea level and ERS wind stress data. At the eastern boundary, Kelvin waves are observed to reflect into first-mode Rossby waves with a reflection efficiency of 75% of that of an infinite meridional wall. However, reflected long Rossby wave amplitudes are observed to decrease strongly while propagating westward. Indeed, west of 110W, the Rossby signal is mainly dominated by wind forced Rossby waves and not by Kelvin reflection at the eastern boundary. This result dismisses the role of eastern boundary Kelvin wave reflection as a major contributor to the Rossby signal in the central Pacific. At the western boundary, the reflection of the first two Rossby waves does explain most of the Kelvin wave variance. The large contribution of the second Rossby wave reflection to the Kelvin wave illustrates the crucial role played by the Papua-New Guinea asymmetric coasts close to the equator. A spectral analysis of the wave and wind signals in the western Pacific shows that the first three Rossby waves propagating west of the dateline are mainly wind forced near the dateline at periods of two to four years. Finally considering only the low-frequency component of the wave signal, the reflection efficiency at the irregular western Pacific ocean boundary (mainly the Borneo/Indonesia/Asia and Australia/New Guinea land masses) is estimated to be around 50% of that which would be reflected from a solid meridional wall.

A STUDY OF SCALE INTERATION IN THE ANOMALIES EQUATORIAL ATLANTIC

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Different simulations of the interanual variability of the tropical Atlantic are intercompared. While the evolution of the episodic warmings/coolings is monitored through the zonal and meridonal sea surface temperature anomalous gradients, the generation of the events is better represented in terms of the anomalous heat content of the surface layers. Thorugh model output statistics, this heat content can be related to other features of the simulation, like mixed layer depth, or surface currents. The interaction between scales is studied. by including among other variables, some derived from the forcings (anomalous wind stress and curl) through integration.

A ESTUDYN OF HYDROLOGIC VARIABLITY OF DOURO RIVER BASIN

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Recently, the study of climate variability in the Iberian Peninsula has attracted considerable interest. Knowledge of behaviour and evolution, in space and time, of the mathematical series, which correspond to the different climate elements, is important due to its social and economic repercussions. In this respect, the flow series and precipitation series are of particular importance.

In this study, the variability exhibited by those series at the Douro River Basin, as well as the analysis of the principal rotated and unrotated components series and precipitation series are investigated.

Flow and precipitation have been simulated as a function of both altitude and the estimated laplacian of the altitude. The results obtained with the models allow us to relate flows and precipitation to the geographic pattern of the region.

The application of spectral method (Rapid Fourier Transform) have also shown oscillations which are characteristic of flow and precipitation.

A GENERICALLY INTRASEASONAL SOUTHERN OSCILLATION OF THE ATMOSPHERE–LAND SYSTEM?

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The Southern Oscillation (SO) has recently been found to possess a structured low-frequency (LF; 4–7 year) band. Coexistence of at least two related modes throughout the century has been confirmed by the present author in a study of the modal structure of Indian monsoon time series. There is reasonable suspicion that one of these modes might correspond to a phenomenon found a couple of years ago in an in-depth empirical study of the attracting manifold of a coarse-resolution, two-layer, tropospheric General Circulation Model (GCM): A self-maintaining, generically intraseasonal Southern Oscillation of the atmosphere-land system that develops at the GCM's attractor sets under boreal post-midsummer conditions—although temporally fixed SST fields are applied. The nature, occurence and performance of this SO and of its interannual LF 'daughter' mode are presented in detail, and Indian summer monsoon (ISM) as well as SO time series of the GCM are analyzed in view of their respective interannual to interdecadal modal structures. Internally generated, centennial-scale variability that exhibits 'epochal' character is traced back to constructive interaction across the annual forcing scale of ISM retreat dynamics resulting in a biennial mode, the annual forcing itself, and the SO. Preliminary comparison to observed modal structures of both ISM and SO is made in view of a potential method of GCM verification.

ON THE MODAL STRUCTURE OF INDIAN MONSOON ONSET

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As start-up of a two-week episode that results in establishment of the Indian summer monsoon (ISM), onset over Kerala (MOK) is not only an economically important reference signal but signifies also a key singularity of the global seasonal cycle. Sampled annually once at intersection between climate regimes, monsoon onset and retreat series are generally viewed here to represent natural Poincaré sections that might help dismantling topologically relevant climate information. A complex dynamical picture is inferred from the scarce data base provided by high-quality MOK, northeast monsoon onset (NEMO), and ISM retreat series which are available for different timespans of the 1870–1990 period. Synchronized with an 8 year mode, the densely populated 2–3 year band exhibits three marked components centered by a 2.24 year mode that leads NEMO. A relatively strong 11 year NEMO mode is growing throughgout the century. Prominent MOK modes of the 4–7 year band are argued to belong to distinct atmosphere–land and atmosphere–ocean oscillators. MOK/NEMO phase relationships carried by the latter underwent systematic changes during the 20th and 50th. apparently controlled by modified beat periods. Both sunspot and double (Hale) cycles appear to be unimportant in the dynamic organization of the climate system as reflected in these series. Frequency relationships and their changes tend to follow selection rules of the Farey (continued-fraction) tree. Two climate fluctuations of the century, standing out as shifted means in both MOK and NEMO, indicate decadal–scale interhemispheric mass displacement apparently related to the status of the North Atlantic Oscillation.

GLOBAL CIRCULATION PATTERNS ASSOCIATED WITH ATMOSPHERIC FORCING BY SEA SURFACE TEMPERATURE

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In this study an assessment is made on the interannual variability of the atmospheric circulation simulated by an R21 version of the Melbourne University AGCM. For this purpose, covering the period 1979-88, an ensemble of 10 independent simulations has been produced, the model being forced by prescribed fields of observed sea surface temperature and sea ice cover. Internal and forced variabilities were analysed throug use of a 3-D normal mode expansion scheme of geopotential and wind fields, allowing a separation between barotropic and baroclinic as well as gravitic and rotational components. A complex principal component analysis (C-PCA) was then performed on barotropic and fourth baroclinic modes, associated with both internal and forced variabilities. With respect to modes associated with internal variability, the PNA teleconnection pattern appears as the first global EOF for both barotropic and fourth baroclinic modes. In the case of modes associated with forced variability, C-PCA reveals as first EOF patterns resembling the one proposed by Karoly (*1989, J. Climate, 2*) in the case of barotropic and the Walker Circulation in the case of fourth baroclinic mode. PCs associated with two forced patterns present high values of correlation (resp. 95% and 97%) with the *cold tongue* El Niño index. Results of projections of global NCEP reanalysis (1973-96) onto forced patterns, as well as correlations with an El Niño index, will finally be presented.

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ROLE OF INDIAN OCEAN SSTs ON THE ASIAN SUMMER MONSOON

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There is evidence that a link exists between ENSO and the Asian summer monsoon, but the mecanism is not known clearly, particularly the respective parts of variability of the monsoon explained by remote or local impact of the SSTs. For the third year of the EEC funded SHIVA project, we propose to investigate the role of Indian ocean SSTs on the summer monsoon. For this purpose, we run the ARPEGE/CLIMAT GCM, developed at Météo-France. The model is forced with composite global SSTs. These composite fields are based on all the 9 possible combinations of climatological SSTs, 1987 and 1988 observed SSTs specified separately for the Indian and Pacific ocean basins. A T31 troncature (grid spacing of 3.8°) has been choosen for this experiment, giving a satisfactory representation of the Asian summer monsoon at a low computational cost. The period of integration starts on the last day of February and finishes at the beginning of October, so as to cover the entire period of the Asian summer monsoon, including onset, mature phase and retreat.

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Analyses of monthly mean sea surface temperature (SST) from different coupled global circulation models (GCMs) were conducted. The simulations employ a hierarchy of ocean and atmosphere models which differ in the spatial resolution and in the processes simulated in the ocean models. The frequency spectra of the SST anomalies are basically dominated by the red noise characteristics of a AR(1)-process, but the GCM simulations also show signifcant differences from that of a AR(1)-prozess over large regions. In general, a steeper slope relation to the expected omega to power(-2)-slope is found in the GCM simulations. This can be attributed to internal low frequenzy variability of the atmosphere and/or to atmosphere-ocean interactions. The differences due to atmosphere-ocean interactions are important for interannual and decadal SST variability and predictability. They will be further investigated and discussed in this talk.

THE INFLUENCE OF SOLAR VARIABILITY ON THE VARIABILITY OF THE CLIMATE SYSTEM

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The role of solar variability as a cause of decadal to centennial climate change is still a topic of debate. We assess the response of a coupled General Circulation Model (GCM) to an estimate of the solar variability since 1700, and to a series of idealized sinusoidal solar forcings with periods ranging from 11 to 160 years and amplitudes ranging from 0.5 Wm^{-2} to 6.0 Wm^{-2}, superimposed on a constant forcing of 1365 Wm^{-2}. The reponse to a variable solar forcing is compared to the internal variability resulting from large-scale ocean-atmosphere-sea-ice interactions. It is found that locally, and on the regional scale, the internal variability dominates and that a variable solar forcing hardly affects the dominant modes of variability and their explained variance. On the continental to global scale however, and averaged over periods longer than 30 years, the solar-induced variability dominates internal variability in the averaged, annual mean surface air temperature (SAT). This seemingly contradictionary result can be explained by the fact that the internal modes of variability are only weakly correlated with changes in globally averaged, annual mean SAT. The latter is a consequence of the structure of all the internal modes of variability, which are characterized by patterns of both positive and negative temperature anomalies.

HIGH AND LOW FREQUENCY INTRASEASONAL VARIANCE OF OLR ON ANNUAL AND ENSO TIME SCALES

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Using 20 years of outgoing longwave radiation (OLR) observations, the complex behaviour of the higher (6-25 day) and lower (25-70 day) frequency bands of tropical intraseasonal convective oscillations is investigated over the tropical and subtropical Indian and Pacific Oceans (including Australasia). Emphasis is given to the mean annual cycle and to the interannual variability of both bands on ENSO time scales, as well as to the interaction between the two bands. The strongest intraseasonal signals are, for the most part, aligned with the Intertropical Convergence Zone (ITCZ) and South Pacific Convergence Zone (SPCZ). In some cases, the 6-25 day signal is not co-located with the Madden-Julian Oscillation (MJO) signal and/or occurs remotely from the ITCZ. Over the equatorial eastern Indian Ocean, strong activity in both bands persists throughout the year, but the bands are found to be anti-correlated, regardless of the ENSO phase.
The effect of ENSO time scales is further examined by looking at DJF anomalies for five El Niño and two La Niña events during our 20-year sample. A well-defined response of the two bands is restricted to the northwestern and central Pacific. Over the northwestern Pacific Ocean the two bands complement one another with suppressed (enhanced) convection occurring during El Niño (La Niña) events. Both bands also complement each other over the equatorial central Pacific, but are out-of-phase with those in the western Pacific on ENSO time scales. In contrast, over the Australian monsoon region and the eastern Indian Ocean, neither band shows a uniform response in terms of anomalous activity when the latest five ENSO warm events, 1977-78, 82-83, 86-87, 91-92 and 92-93, are considered.

QBO SIGNALS IN THE MONSOON SYSTEM IN GCM EXPERIMENTS

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In order to study the relationship between the QBO and the monsoon system, GCM experiments have been performed, using the ECHAM4 T42-L19 model, where the QBO was assimilated by a linear relaxation technique. A comparison of experiments with opposite phases of the QBO, but otherwise equal boundary condition, showed a linear relationship between the change in cloud amount and change in temperature at 100 hPa in regions of deep convection. The QBO related signal in OLR cloud forcing reinforces the QBO induced temperature signal at the tropopause further, thus providing a positive feedback mechanism. The resulting difference in precipitation between the easterly QBO and westerly QBO experiments reaches 100 to 150 mm/month in the equatorial Indian Ocean in winter and in the tropical western Pacific in summer. Thus the experiments show that the QBO, which is driven by tropical waves with periods of a few days, contributes substantially to the interannual variability of the monsoon system. This may help to explain observed biennial components of the variability of the tropospheric circulation.

THE INTERANNUAL VARIABILITY OF THE MADDEN-JULIAN OSCILLATION IN AN ENSEMBLE OF GCM EXPERIMENTS.

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The interannual variability of the Madden-Julian Oscillation (MJO) is investigated in an ensemble of 15 experiments performed with the ECHAM4 T30 GCM. The model experiments have been performed with AMIP conditions from January 1979 to December 1993. The MJO signal has been identified by means of a Principal Oscillation Pattern (POP) analysis applyed to the normalized ensemble anomalies of the 200-mb equatorial velocity potential.
Some evidence of a sensitivity of the simulated MJO activity to the sea surface temperature (SST) over the equatorial Indian Ocean and Pacific is found. The interannual variability of the simulated oscillation, in fact, appears to be significantly correlated with the equatorial SST in the Indian Ocean. The results indicate also a clear influence of the El Nino/Southern Oscillation phase on the spatial distribution of the intraseasonal oscillation activity . During the warm phases of ENSO, the largest activity appears to migrate eastward into the central Pacific, whereas, during the cold phases, the strongest activities are confined in the western Pacific.

ASSESSING THE INFLUENCE OF ENSO FORCING ON SYNOPTIC ACTIVITY IN THE TROPICAL ATLANTIC.

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The tropical Atlantic Hurricane season of 1997 was unusually inactive. Given that the Sea Surface temperatures (SSTs) in the tropical Atlantic were slightly warmer than the long term mean during the Hurricane season, this is somewhat surprising. It has been suggested the large amplitude El Niño, occurring simultaneously in the tropical Pacific, contributed to the relative inactivity in the Atlantic. Physical mechanisms for how this can occur are unconvincing. A hierarchy of General Circulation Models and high resolution Limited Area Models along with available observational data sets, will be used to assess the influence of the tropical Pacific on the tropical Atlantic . Results will be reported indicating by which mechanisms anomalies in the tropical Pacific SSTs can directly influence synoptic activity in the tropical Atlantic.

MODIFIED ERTEL'S POTENTIAL VORTICITY AS A CLIMATE VARIABLE

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Existing arbitrariness in Ertel's potential vorticity (PV) definition is used to arrive at an "optimal" PV modification which refers to minimum (in the least squares sense) of the material time-rate of change of PV due to diabatic heating an friction. Simultaneously, a problem of determination of an idealised atmospheric climate state with the highest possible degree of annihilation of diabatic and frictional PV forcing is solved. A minimisation procedure is applied to a difference of informational entropy (IE) values between actual air mass distribution on PV values over each Hemisphere and the corresponding statistically equilibrium (Boltzmann) distribution and used for searching for optimal PV definition. Method efficiency is shown, using monthly-mean January and July statistics for 1980-89 years period (ECMWF data). Interannual variations of statistical characteristics of the optimally modified PV field are analysed and related to air changes over Antarctic and Arctic in the 1980s.

CONTRIBUTION TO THE ANALYSIS OF IBERIAN PENINSULA CLIMATE VARIABILITY

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The atmosphere and its climatic mean state are constantly evolving on many time and space scales. Our research in Iberian Peninsula is devoted to identifying regimes on intermediate time scales, on the order of several years to decades, in the hope that their presence can be used for understanding and possibly predicting climate fluctuations.
The method of principal component analysis is applied to link together spacial and temporal components of air temperature and precipitation in Iberian Peninsula. The variability of these climatological fields are broken into several orthogonal patterns, each one explaining a fraction of the total temporal variance. These ranked patterns are analysed and possible physical processes are assigned to the predominant eigenvectors.
A selected network of more than one hundred weather stations with records between 1960 and 1990 is used as data base to isolate the principal modes of variability of temperature and precipitation fields in Iberian Peninsula.

Sensitivity to resolution studied with a variable horizontal resolution global circulation model

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The atmospheric general circulation model ARPEGE used at METEO-FRANCE for climate studies is a spectral model that offers the possibility of varying the horizontal resolution. This allows to increase the resolution over the region of interest while keeping a reasonable cost in computer time.However, this technique may be non-isotropic when the contrast between the highest and the lowest resolution of the streched grid is strong. This problem becomes critical when the model's physical parametrizations are quite sensitive to the horizontal resolution. In the present study, numerical simulations are performed with the stretched version of ARPEGE-Climat in order to investigate the resolution dependence of moist processes and precipitation simulated by the variable resolution model with idealized boundary conditions corresponding to an "aquaplanet". The Earth is covered with an ocean whose prescribed surface temperature has a zonally symetric latitudinal distribution. Simulations bring to the fore some disymetric structures along the equator, due to the varying resolution. Such results are very sensitive to the choice of some physical parameterizations, such as the cloud scheme or as the closure's condition in the convective scheme.

SEASONAL FORECASTS WITH A COUPLED AOGCM.

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Research activities have been conducted at Météo-France in the field of seasonal predictability with ARPEGE atmospheric GCM, as part of PROVOST program. In these studies ARPEGE is forced with analyzed observed SST.

A new set of experiments have been recently realized in order to determined the impact on long-range predictability when ARPEGE GCM is coupled with the LODYC-OPA7 ocean model, but only over a limited area (the tropical Pacific region "TDH"). We have studied 4 winter cases (JFM averages from 1990 to 1993, after a December spin-up period). There is 9 experiments for each year, with a shift varying from 1 to 9 days before the 1st December, for both atmospheric and oceanic restarts.

Results will be presented and comparisons will be made between the two set of uncoupled and partially coupled experiments, in terms of

(i) possible seasonal drift induced by changes in SST over the coupled area ;

(ii) probable increase in intra-seasonal variability caused by the new degree of freedom brought by the coupling ;

(iii) expected change in the objective scores computed when comparing the climatology and the experiments.

RELATIONS BETWEEN NAO, PNA, AND ENSO OSILLATIONS IN SEASONAL WINTER SIMULATIONS WITH FOUR AGCMs

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In the framework of the European project PROVOST (PRediction Of climate Variations On Seasonal and interannual Timescales), nine simulations of each of the winter seasons of the period 1980-1994 have been performed with four different atmospheric models in SST-forced mode : the UKMO model, the ECMWF model, Arpege Climat model of Météo-France (T42), and Arpege Climat with a higher resolution of T63 (this latter set of simulations being calculated at EDF). This provides an important multi-model ensemble to study the reproduction of the main low frequency oscillations occuring at extratropical latitudes (PNA and NAO patterns) and their possible modulation by different oceanic factors. We identify clusters or modes of atmospheric low frequency variability in these sectors and we look for typical structures of the oceanic forcing associated to each of these atmospheric patterns. A particular attention is paid to the possible modulation of the NAO by different possible external sources : NAO-PNA interactions, extratropical or tropical oceanic forcing influence on the NAO (in particular : interactions with the three El Niño and one La Niña events involved in the period studied).

THE ROLE OF LAND SURFACE PROCESSES IN INTERANNUAL VARIABILITY OF THE LMD GCM.

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The Asian Monsoon displays substantial interannual variability which has profound social and economic consequences for the people of India and South East Asia. An understanding of the causes of this interannual variability is central to future success in seasonal and longer term prediction. The aim is to diagnose interannual variability in the LMD GCM and to explore the links between the regional and large scale aspects of interannual variability. Various mechanisms have been proposed to explain the interannual variability of the monsoon. These include land surface processes and Eurasian snow cover. Although weak monsoons are frequently associated with El Niño, the correspondence between the strength of the rainfall and the strength of ENSO is relatively weak. Part of the variability in this relationship may result from other slowly varying boundary conditions, such as soil moisture, vegetation and Eurasian snow cover. The aim of this study, is to identify the role of land surface processes anomalies, particularly in the months preceding the monsoon, in determining the interannual variability of the monsoon, including their relationship with ENSO.
The results of an ensemble of six integrations for the years 1950-1994 with the complex land surface scheme (Sechiba) and an integration for the same years with a simplified land surface scheme are used. Our aim is to characterize the forced and internal variability and the impact of the change in land surface processes on these vari abilities.

THE DYNAMICS OF EURO-ATLANTIC BLOCKING ONSETS

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The low-frequency extratropical variability is highly influenced by the occurrence of some particular large scale circulation flow patterns, the weather regimes. The mechanisms leading to one of those regimes, the euro-atlantic blocking, are investigated using observed data and outputs of a simple QG model. A large scale and small scale composite analysis indicates that euro-atlantic blocking events have two simultaneous precursors identified on both observed and simulated data: a high latitude retrograding wavenumber one pattern at planetary scale and an enhanced baroclinic wavetrain traveling across North Atlantic at synoptic scale. The question whether the two above precursors are necessary and sufficient conditions to trigger euro-atlantic blocking is addressed by performing various sets of initial-value experiments performed with the quasi-geostrophic model.

ON THE INFLUENCE OF NORTH ATLANTIC SST ANOMALIES ON THE ATMOSPHERE

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A satisfactory understanding of how mid-latitude SST anomalies influence the atmospheric circulation has remained remarkably elusive. Past studies of this problem have yielded divergent results. There is, however, a good deal of evidence to suggest that the time mean reponse can only be understood by reference to changes in the high frequency transients; that is, to changes in the frequency, intensity, or spatial distribution of mid-latitude weather systems.
We are investigating the influence of SST anomalies on the statistics of Atlantic weather systems. We have carried out a large ensemble of integrations with the UKMO atmosphere GCM and are focussing in particular on the influence of SST anomalies in a key region of cyclogenesis off the SE coast of the U.S.A. Changes in sensible and especially latent heat flux in this region due to changes in SST could modulate the strength of the North Atlantic Storm Track which could influence low frequency variability such as the North Atlantic Oscillation. We will report results from seasonally varying integrations through the northern mid-winter and spring.

NATURAL CLIMATE VARIABILITY ON ALL TIME SCALES FROM A STOCHASTIC ATMOSPHERE-OCEAN MODEL

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After removing annual variability, power spectral analyses of local atmospheric temperature from hundreds of stations and ice core records have been carried out from time scales of 10^{-2} to 10^{6} yr. A clear sequence of power-law behaviors is found as follows: (1) from 40 ky to 1 My a flat spectrum is observed, (2) from 2 ky to 40 ky the spectrum is proportional to f^{-2} where f is the frequency, and (3) below time scales of 2 ky the power spectrum is proportional to $f^{-\frac{1}{2}}$. At time scales less than one month we observe that the power spectra of continental stations become proportional to $f^{-\frac{3}{2}}$ while maritime stations continue to have power spectra propotional to $f^{-\frac{1}{2}}$ down to time scales of one day. To explain these observations, we model the vertcial transport of heat in the atmosphere as a stochastic diffusion process. The power spectrum of temperature fluctuations at the earth's surface expected from this model equation in a two-layer geometry with thermal and eddy diffusion properties appropriate to the atmosphere and the ocean and a radiation condition at the top of the atmosphere agrees with the observed spectrum. This model can be used as a null model against which to test for the presence of periodicities and anthropogenic effects on the climate system.

COUPLED MODES OF VARIABILITY BETWEEN SURFACE TEMPERATURE IN PORTUGAL, 500 hPa HEIGHT AND SEA-LEVEL PRESSURE

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A long-term climatological analysis is performed over non-seasonal standardised monthly means of surface temperature at 15 stations in Portugal, 500 hPa height (Z500) and sea-level pressure (SLP) for a region including North Atlantic and Western Europe, covering a period of 34 years from June 1955 to May 1989. A Principal Component Analysis was performed and, as expected, leading PCA modes showed to be in good agreement with the synoptic-climatological experience as well as with results from previous works. In order to relate surface temperature variability with large scale circulation characteristics, a direct Singular Value Decomposition (SVD) as well as a Canonical Correlation Analysis (CCA) were applied to surface temperature and either Z500 or SLP fields, allowing to isolate pairs of spatial patterns that tend to synchronously occur. A multiple linear regression model was then developed between first PC of temperature and two sets of three best correlated PCs of Z500 and SLP. The CCA was used as the fitting process, obtained canonical correlation coefficient reaching 65% for the first mode. Predictions were performed and obtained values of statistics that measure forecast skill indicated acceptable results. Quality of obtained predictions using a cross validation scheme was finally evaluated through use of skill scores, allowing to conclude that this model has a better performance than either climatology or persistence.

THE RECENT ABATEMENT OF EASTERLY WINDS IN THE NORTHERN ADRIATIC

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Easterly winds from the northern Adriatic contribute, together with atmospheric depressions and the often decisive blowing of southerly winds from the southern and middle Adriatic, to produce damaging sea surges in the Gulf of Venice. A new statistical analysis of three-hourly wind records from Trieste for the period 1951-1997 has shown a clear decline in the strength of bora and other easterlies. This abatement is not accompanied by a strengthening of winds from other directions, but by more frequent calm situations (from 26% of total observations in the 1950s to 44% during the last ten years, and even to over 60% during the early 1980s). Similar (though weaker) declining trends for the easterlies have been recorded at other stations in the northern Adriatic (Ronchi, Venice). An inspection of previously published data from Trieste suggests that such trends may have been going on, possibly with minor fluctuations, since at least the beginning of regular instrumental records, in the late 1860s. Such changes in wind pattern, which have favourable effects on the frequency of coastal flooding, may be due, at least in part, to interdecadal climate variability. However, the persistence of certain trends suggests variability over a longer time scale, with in particular less frequent situations with strong atmospheric pressure gradients between highs in central/eastern Europe and lows in southern Italy or in the Adriatic area.

SOME QUANTITATIVE SIGNATURES OF CLIMATE VARIABILITY ON TIME SCALES OF SOLAR FORCING

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In spite of advanced knowledge in the field of weather systems, the adequate climate scenarios intend deeper insight into the drivers of climate changes. The overcentennial records available for such meteorological parameters as an air temperature T and precipitation totals P allow to judge their evolution on time scales of solar forcing, a quantitative basis being applied. The interannual, annual, decadal and secular variations are discussed from the viewpoint of possible modulation. Although the uncertainties are significant enough due to quite a large scatter of ΔT and ΔP fluctuations, the modulation features in their profiles are unambiguous and persistently documented by data from a number of European meteorological stations. Their mutual comparison in terms of peculiarities of T and P development averaged within different portions of a year gives some idea as to the ways how to enhance the confidence level of prediction of climate changes in future.

THE ENSO SIGNATURE ON WINTER RAINFALL OVER THE IBERIAN PENINSULA

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The strong ENSO event currently underway has been drawing much attention due to its impacts world-wide. This study investigates de influence of the ENSO phenomenon on the winter rainfall over the Iberian Peninsula. The analysis is based on observed rainfall data and on an ensemble of ten 10-year long simulations with prescribed AMIP SSTs and sea-ice coverage generated by the Melbourne University General Circulation Model (MUGCM). Each of the 10 simulations started from different initial conditions randomly obtained from an earlier 30-year control simulation. Results show that, in average, ENSO is associated with weak negative regional rainfall anomalies (-10 %) both in the observations and in the model. However, the ENSO signature over the region for distinct events varies substantially. Winter rainfall appears to be weakly influenced by ENSO. The high intra-seasonal and intra-regional variability of winter rainfall also confirms the weak ENSO signal and the chaotic nature of rainfall in the region.

VARIABILITY AND INTERACTION OF THE GLOBAL ATMOSPHERE CIRCULATION FORMS OVER THE ATLANTIC AND EUROPEAN SECTORS OF THE NORTHERN HEMISPHERE IN WINTER

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Investigation of the synoptic and global variability of the atmosphere circulation types over the Atlantic and European parts based on the parameters of the middle troposphere carried out. We considered the consecutive change of the various types of the atmospheric processes using Dzerdzeevsky's classification. Indexes of the atmosphere circulation calculated by the different methods were studied as one of the important characteristics of the predominant circulation regime. Amplitude-phase characteristics of the indexes were accounted by using original method proposed by Reva (1995).
We studied as simple circulation mechanisms make zonal and meridional types of the atmospheric processes. The results allowed to determine structure of the natural synoptic seasons and distinguish the intraannual stages of the atmospheric processes. Such approach gave us a possibility to investigate the characteristics of the winter circulation epochs over the Atlantic ocean and Europe for the period from 1950 to 1990.

WAVE PACKETS OBSERVATIONS IN THE EARTH'S CUSP REGION, AT THE MAGNETOPAUSE, AND INSIDE OF THE PLASMA SHEET BY THE MEASUREMENTS ON BOARD OF INTERBALL-TAIL PROBE.

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A new method of the wave analysis based on the idea of two types of the vector variables correlative dependencies ('scalar' and 'vector' ones) have been developed and applied to the magnetic field data obtained on board of the INTERBALL-1 satellite. This method allows to do the efficient spectral analysis of vector variables and rapidly find the wave vectors angular distribution and polarization states of the electromagnetic and magneto-hydrodynamic plasma waves. The low frequency wave properties was studied in the three different regions of the magnetosphere: in the high-latitude cusp region, at the magnetopause, and in the plasma sheet, during the higher level of wave activity (partially bounding with substorms). The discrete wave packets are characteristic for the low frequency variations in all these regions. Various events differ one from another by the wave mode composition. The ion-cyclotron wave packets corresponding to various ionosphere ion species are found in the high altitude cusp region and in the tail plasma sheet. In contrast, the spectra composed completely from packets of the linearly polarized compression mirror waves were observed nearby the high latitude magnetopause in time of the strong magnetosphere compression under the blow of the high density plasma cloud coming from the Sun on January 11, 1997.

INTERANNUAL VARIABILITY OF THE OCEAN-ATMOSPHERE SYSTEM THROUGH GLOBAL GENERAL CIRCULATION MODEL RESULTS: THE PACIFIC OCEAN

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A Coupled General Circulation Model is used to study the interannual variabilty of the climate system of the global domain with a focus on the Pacific Ocean. Two simulations are analysed in order to compare the effects of the parametrisation of the lateral diffusion in the ocean model (horizontal versus isopycnal diffusion).
Sophistaticated analysis tools such as Multichannel Singular Spectrum Ananlysis and Canonical Correlation Analysis are used to perform these analyses.
We focus our attention on the El Niño phenomenon particularly present in the isopycnal run. The goal of the work is to better understand the processes responsable for the spatial and temporal pattern of the phenomenon. The two simulations, differing only by their ocean physics, don't show the same oscillations. It can attributed to a different mean state and to the dynamics associated with the isopycnal diffusion. In this way, the role of the salinity may be non negligeable. The connections with the northern and southern midlatitudes are also discussed.

THE SOIL-PRECIPITATION FEEDBACK: A STUDY WITH A REGIONAL CLIMATE MODEL

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Monthlong integrations with a regional climate model are utilized to study the sensitivity of the summertime European precipitation climate with respect to the ambient soil moisture content. Experiments are conducted for July 1990 and 1993. For each of the two months, the control experiment is compared against two sensitivity experiments with dry and wet initial soil moisture distributions. These experiments yield pronounced differences in the precipitation climate, and suggest that the location of the boundary between the wet Atlantic climate to the north, and the dry Mediterranean climate to the south, is heavily affected by the continental-scale initial soil moisture content. The investigation of the mean daily cycle throughout the integration period demonstrates that the physical mechanism underlying the soil-precipitation feedback is related to the development of the diurnal boundary layer and its interaction with soil, boundary layer, radiative and convective processes. Over moist soils, these processes act in concert to yield higher values of the moist entropy in the early afternoon boundary layer, and thereby to increase the potential for convective activity. The results suggest that soil moisture is a major factor affecting the summertime European precipitation climate, with implications for the seasonal cycle and the interannual variability.

INTRASEASONAL VARIABILITY OF THE INDIAN MONSOON

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The intraseasonal variability of the Indian Monsoon can be thought of as alternating active and break periods associated with two distinct preferred locations of the tropical convergence zone (TCZ), over the Indian sub-continent and over the equatorial oceanic region. Using the ECMWF re-analysis (ERA) data set for 1979-1993 a "climatology" of the active and break regimes has been produced. This has been done by spatially averaging daily precipitation data over two regions associated with the two preferred locations of the TCZ. Using these daily spatial averages, active and break periods have been identified and their composite structures examined. It is found that active and break periods have significantly different flow regimes associated with them over a large region in both the upper and lower troposphere. The different diabatic heating stuctures associated with the two regimes have been used to drive a simple numerical model and the resulting structures compared with the "climatology". The next stage is to run the model with the proportion of active and break heating determined by the flow itself.

A CLIMATOLOGY OF ONSET DATES OF THE ASIAN SUMMER MONSOON

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Synoptic and intraseasonal variability lead to variations of the onset date of the Asian summer monsoon, and blur the predictability of this and other vital events like active/break phases. An objective method is used to find local onset dates and break days from daily precipitation and 850 hPa winds of the ECMWF reanalysis and an AMIP-type simulation of the same resolution (T106). The method uses local July precipitation as a threshold to cope with the high spatial variability and the biases in both ERA and ECHAM precipitation. The onset date lines are found to be sensitive on two different criteria for precipitation (3 consecutive heavy rain days vs. five day running means). The high resolution model ECHAM4 simulates a very realistic low level jet over the Arabian Sea both in strength and timing. Still, the onset in central India occurs a week earlier than in the reanalysis. Whether this and other biases of monsoonal precipitation are due to the land surface scheme, the convective parameterization, or the lack of realistic air-sea interactions is unknown.

ON THE PREDICTABILITY OF INTERANNUAL VARIATIONS IN THE ACTIVITY OF THE MADDEN JULIAN OSCILLATION.

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The Madden-Julian Oscillation (MJO) is the dominant mode of tropical variability at intraseasonal timescales. It displays substantial interannual variability in intensity which may have important implications for the predictability of the coupled system. Using the NCEP 40-year Reanalysis and the results from a 4-member ensemble of 45 year integrations with the Hadley Centre climate model, forced by observed SSTs for 1949-94, the relationship between MJO activity and SST has been investigated. The implications of the results for the predictability of the tropical ocean-atmosphere system will be discussed.

THE PACIFIC COLD TONGUE AND THE ENSO MODE IN A FULLY COUPLED ZEBIAK-CANE MODEL

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The equatorial Tropical Pacific Climate system is a delicate coupled system in which winds driven by gradients of sea surface temperature (SST) within the basin interact with the ocean circulation to maintain SST gradients. This results in a time-mean state having a strong zonal temperature contrast along the equator with an eastern cold tongue and a western warm pool. By the same coupled processes also interannual variability, known as El-Niño/Southern Oscillation, is present in the Pacific. This variability can be attributed to an oscillatory coupled mode, the ENSO mode, in the equatorial ocean/atmosphere system. When the amount of windstress per SST, i.e. the coupling strength between the ocean and atmosphere, is changed this affects both the annual mean state and the ENSO mode. Using a Cane-Zebiak type intermediate coupled model, these linked features of the Pacific Climate are unified into one framework. The ENSO mode arises as a robust oscillatory mode on a coupled mean state and becomes unstable at sufficiently large coupling strength. The origin of this mode, its propagation mechanism, its relation to the spatial structure of the annual mean state and the interaction between the ENSO-mode and the seasonal cycle are considered.

NUMERICAL STUDY OF THE IMPACT OF FIRST EIGENMODES OF SST VARIABILITY ON TROPICAL RAINFALL

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The 4 first EOF of Sea Surface Temperature Anomalies (SSTA) are sufficient to document main spatial structures of SST variability known to influence tropical rainfall. Each of these spatial structures is concerned with privileged time-scales. Thus linear combinations of these modes allow the construction of idealised SSTA patterns involving different time-scales. Numerical experiments performed with the AGCM ARPEGE-Climat (CNRM, Météo-France) using these patterns enable to investigate SSTA-related changes in rainfall and atmospherical circulation in the Tropics. The relative impact of ENSO and decadal scale SST variability of the global ocean as well as the meridional gradient of SSTA in Tropical Atlantic are investigated. Special focus is made on three areas of interest : Nordeste, Southern Africa and Sahel.

THE IMPLEMENTATION OF A NONLOCAL DIFFUSION MODEL IN THE HOPE OGCM

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A nonlocal diffusion model, Large et al (1994), is implemented in the Hamburg Ocean Primitive Equation model (HOPE) to establish an improvement in the simulation of mixed-layer dynamics in OGCMs. Preliminary results show that, as compared to the the original mixed-layer parametrization of HOPE, differences are found in equatorial regions. The existence of barrier layers becomes apparent in the warm pool region of the West Pacific. Also a change in magnitude and location of the equatorial currents is found. Finally a change in the density structure has an effect on the velocity of baroclinic equatorial waves. In the near future the performance of the nonlocal diffusion model will be evaluated against a bulk mixed-layer model and the results will be compared to data from observations.

TRACKING DOWN THE CAUSES OF THE 1997 EL NIÑO WITH AN ADJOINT OGCM

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The adjoint of the ocean general circulation model HOPE is used as a tool for investigating the causes of the 1997 El Niño. The adjoint computes the derivatives of the NINO3 index N_3 to the forcing fields $\mathcal{F}(t)$ used by the ocean model (wind stress, heat and moisture) and the initial state X_0 (temperature, sea level, salinity and currents). Adjoint Kelvin and Rossby waves can be identified in the sensitivities to sea level and wind stress at earlier times, which can be traced back for more than a year through western and weak eastern boundary reflections. The sensitivities to the heat flux and SST are local and decay in about a month.
Approximating the observed anomalies as small deviations from climatology, $N_3(T) \approx \partial N_3/\partial X_0 \cdot \delta X_0 + \sum_{t=0}^{T-1} \partial N_3/\partial \mathcal{F}(t) \cdot \delta \mathcal{F}(t)$, we can decompose the rise in the NINO3 index in the model during late spring 1997 into contributions from the various westerly windbursts (ECMWF wind stresses in December/January, March and April), other fluxes, and the preconditioning of the ocean at the beginning of December 1996 (ECMWF analysis).

INFLUENCE OF NAO INDEX TO SYNOPTIC WEATHER SITUATION OVER SWITZERLAND

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Fifty years of daily synoptic weather situations over the central part of the Alps are considered. The Alpine region is a transition zone between the Atlantic weather regime, a continental regime and the regime of the Mediterranean Sea and, therefore, sensitive to changes in the large scale weather pattern. To characterize weather systems over Switzerland, Schüepp has defined synoptic weather types adapted to the Alpine region. Although these weather types are manually determined by observers, they are defined by strict rules. Surface pressure and 500-hPa level maps of every day are used to derive parameters identifying Schüepp's weather types. Since the beginning of their records in 1945 pronounced changes in the annual frequency of the weather types could be observed. It is analyzed how these changes might be related to changes in the North Atlantic Oscillation (NAO) index. In winter there is a strong relation between the NAO index and the frequency of so-called high pressure situations. In summer the pressure pattern over the Atlantic influences the regional scale weather type to a much lesser extent.

WESTERLY WIND BURSTS AND TRIGERING OF ENSO.

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The westerly wind bursts are thought to play a key role in ENSO variability. They often result in oceanic Kelvin waves which propagate toward the eastern part of the basin and raise the thermocline toward the sea surface. In this study, we concentrate more on their impact in the western and central Pacific. Analytic westerly wind stress anomalies are introduced at the air - sea interface of a coupled general circulation model. Their local effect is to increase the oceanic turbulence, and to destroy the salinity "barrier layer". The easterly surface currents anomaly results in a significant eastward shift of the western Pacific warm and fresh pool, which is associated with the formation of a thick barrier layer in the central Pacific. This situation might favour the growth of a coupled ocean - atmosphere instability.

DECADAL ANOMALIES OF THE ANNUAL CYCLE IN SST AND SLP FIELDS IN THE NORTH ATLANTIC

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Based on the National Centers for Environmental Prediction (NCEP) data set and the Comprehensive Ocean-Atmosphere Data Set (COADS) analysis of the interdecadal changes of amplitudes and phases of annual cycle in sea level pressure (SLP) and sea surface temperature (SST) fields is carried out. Anomalies of the above mentioned characteristics are estimated for four decades (1951-1990). Spatial distribution of the anomalies of amlitudes of SLP is in agreement with that of the anomalies of decadal mean SLP and positive (negative) anomalies of amplitudes are related to negative (positive) anomalies of decadal mean SLP. During 1951-1960 and 1971-1980 anomalies of phases are not great (approximately 10 days). But decades with the lowest (1961-1970) and highest (1981-1990) values of the North Atlantic Oscillation Index demonstrated the great growth of phase anomalies and their spatial differentiation. Positive (negative) anomalies of phases mean here that, for instance, winter comes later (earlier) than usual. During 1961-1970 the negative phase anomaly (-15 days) is located in the western Atlantic and the positive one (+35 days) near North Africa. During 1981-1990 the situation is reversed - positive (+25 days) anomaly in the western Atlantic, and the negative (-50 days) one near North Africa. Positive (negative) anomalies of amplitudes of SST are associated with negative (positive) anomalies of annual and winter means. Analysis of anomalies of phases of SST have not revealed significant interdecadal changes.

OA17 Climate variability: models and observations (joint with SE)

04 Clouds in the climate system: observations and modelling

Convener: Desbois, M.

VALIDATION OF CLOUD SYSTEMS IN THE GENERAL CIRCULATION MODEL ECHAM4 BY USING THE NUDGING TECHNIQUE

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Clouds are an important regulator of the Earth's radiation budget and present a major link between radiation and the hydrological cycle. We use a different approach to validate clouds in ECHAM4 T106 and investigate the representation of synoptic scale systems in 3 hourly stored data. The aim is to investigate, whether the realistic mean cloud amounts produced by the model are associated with a realistic representation of clouds in a higher temporal resolution. To do this we use the Newtonian relaxation technique (Nudging), which relaxes the model state towards reanalysis data by adding a non physical relaxation term to the model equations.
We present the representation of an extratropical cyclone. Vorticity, divergence temperature and surface pressure are nudged with ECMWF reanalysis fields. The main characteristics of the cyclone are well reproduced by the model. This is true even for variables which are not relaxed. As an example strong cloud cover occurs in frontal and central regions of the surface low and in the upper troposphere the cloud deck is shifted to pre-frontal regions. The investigation shows that the nudging technique is a useful tool for model validation, since model parameterizations can be tested by comparing with distinct observed synoptic situations.

COMPARISONS OF MODEL GENERATED FLUXES WITH SATELLITE INFERRED FLUXES

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For May 1993 and June 1993 radiation budget components at top of atmosphere and at surface were inferred from NOAA-AVHRR and Meteosat data. For the same time period model calculations with the regional model (REMO) were carried out to investigate the energy and hydrological cycle. The investigated area covers the watershed of the Baltic Sea (defined in the BALTEX programme), approx. an area of 1800 x 3000 km^2 with a resolution of 15 x 15 km^2.
To calculate the radiation budget components at surface from remotely sensed data, a complex analysis scheme could be applied, where cloud types as well as their optical properties could also be derived. Before a detailled comparison between satellite inferred results, like fluxes at TOA and at surface or cloud cover, with modelled results could be carried out, the satellite fluxes could be validated with surface observations in advance. This allows to define the achieved accuracies. Based on the different satellite data (NOAA AVHRR - two obs. per day, but high spatial resolution; Meteosat - half hourly resolution, but poor spatial resolution) different intercomparisons will presented.

SIMULATION OF MARINE STRATOCUMULUS EVOLUTION OBSERVED DURING ASTEX: COMPARISON WITH OBSERVATIONS AND SENSITIVITY STUDIES.

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In the "First Lagrangian" of the Atlantic Stratocumulus EXperiment (ASTEX), an air mass was followed for two days while it was advected by the mean wind toward warmer sea surface temperatures . Here, we simulate part of this evolution using the 1-D version of the hydrostatic primitive equation model MAR (Modèle Atmosphérique Régional) developed at the UCL. It includes a high-order turbulence closure, a wide-band formulation of the radiative tansfer and a parameterized microphysics including prognostic equations for water vapor, cloud droplets and rain drops concentrations. Partial condensation is allowed. A 24h simulation is carried out and the results are compared with in-situ measurements of the mean structure as well as the microphysical and turbulent structures. The simulation is sensitive to some external forcings like large-scale subsidence or sea-surface temperature, but also to sub-grid scale process parameterizations, like condensation and precipitation. Several sensitivity experiments will be presented. A particular attention will be given to the impact on surface energy fluxes since these are crucial in coupled ocean-atmosphere models.

CLOUD FIELDS DYNAMICS ABOVE THE CRIMEA

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The investigation is based on a large set of experimental data collected in expeditions in period from 1955 to 1978. Stereophotogrammetric measurements of the main parameters of clouds (such as top and bottom altitudes. rates of horisontal and vertical growth, scales, etc.) provided 1.5% — 3.5% approximation, depending on the type of clouds. During summer expeditions the measurements were made with time intervals from 1 to 30 minutes. A strong dependence of cloud dynamics on the winds direction was discovered. Thus. North-West currents perpendicular to the mountain chain generate wave orographic cloud fields which propagate from the mountain chain to the sea direction for 30 km. Besides, at the coast zone cumulus clouds are strongly influenced by these orographic phenomena while above the sea the clouds become more rarified. This feature explains the difference between the radiational regimes of the open sea and the coast zone.

COMPARISON OF ISCCP C1 AND D1 CLOUD DATASETS

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The importance of clouds in climate has long been recognised and long-term observations are needed to monitor changes in cloud fraction and cloud properties. The ISCCP project provides information on the space-time characteristics of clouds, such as cloud amount, cloud top pressure, and cloud optical depth. These characteristics inferred from the visible and infrared radiances measured by radiometers on various satellites allow clouds to be classified into cloud types. It is expected that the C1 cloud product will progressively be replaced by the improved D1 cloud product. The purpose of this presentation is to point out some resemblances and differences between the C1 and D1 datasets.

A new parameterization of Cloud Properties and comparison of simulated and measured HIRS cloudy radiances

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Accurate modeling of the effects of clouds on absorption, transmission and reflection of thermal energy is crucial. The need for an accurate representation of infrared absorption by clouds is acute since the current uncertainty in this quantity has important consequences on the atmospheric radiation budget. Since the clouds strongly modulate the longwave radiation at the top of the atmosphere, they should be considered as the principal unknown parameter to be inferred in satellite cloud studies. Unfortunately, the exact evaluation of cloud effects require a long calculation time. So, in the spherical particles approximation, the Mie theory was used to develop a new parameterization of cloud optical properties. The scattered and forward trasmissivity and the scattered reflectivity are separately studied and the cloud emissivity is calculated under the energy conservation low. The parameterization is used to compute the cloudy radiances in HIRS/2 channels using the temperature, mixing ratio, liquid and ice content and cloudy fraction profiles obtained from ECMWF. Then cloudy radiances are compared to the one computed using the operational ECMWF emissivity formulation and to actually observed raw TOVS radiances.

BOMEX 1D INTERCOMPARISON: IMPACT OF THE PARAMETRIZATION OF THE SHALLOW CONVECTION ON THE SURFACE FLUXES

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For the "Air-Sea-Ice Interactions" project, simulations of a case from the phase III of the Bomex campaign have been performed. This is a non-precipitating cumulus maritime case. Stationnarized results from the Cloud Resolving Model (CRM) have been used to initialize 1D versions of AGCMs. The participating groups in the intercomparison and the corresponding models were the KNMI (Holland) with a CRM, ECHAM3 and ECHAM4; the LMD (France) with LMD5; the DMI (Denmark); the University of Reading (UK) with the UGCM and the CNRM (France) with Arpège-Climat.
In the Arpège-Climat simulation, the mixing layer is too thick. the BL is too warm and too dry; hence sensible heat fluxes and latent heat fluxes at the surface are not realistic. Moreover, strong temporal oscillations with a $4\Delta T$ period in the surface latent and sensible heat fluxes are generated. The parametrization of the shallow convection is the main source of the errors. The shallow convection is parametrized as a modified Richardson number: an additional term depending on the vertical gradient of the distance to the saturation (term in $L\partial(q - q_{sat})/\partial z$). The absolute value of $\partial\theta/\partial z$ is much smaller than the absolute value of the additional term. Two simple solutions to improve the simulations have been proposed and tested.
A change in the physical parametrizations (use of a statistical cloud scheme) substantially improves the simulation. Both the effects of the liquid water in the vertical diffusion scheme and the parametrization of the direct interactions between the turbulence, the radiation (optical properties of the cloud) and the diabatic processes (condensation/precipitation) are found necessary for a good simulation of the BL.

STUDIES OF UPPER TROPOSPHERIC HUMIDITY USING AIRBORNE IN-SITU SENSORS

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Upper tropospheric water vapour is widely recognised to be of fundamental importance in regulating the earth's climate, despite its low concentrations, because it is a dominant term in the outgoing longwave radiation that cools the planet. Nevertheless, the knowledge of UTH distribution is very limited. This paper presents an on-going study of the performance and measurements of the Fluorescence Water Vapour Sensor, onboard the British C-130 Hercules research aircraft. Our investigations have indicated the necessity of laboratory tests in order to develop a deeper understanding of the instrument's response. These investigations and preliminary results of the tests are shown. Finally, case-study comparisons between the FWVS and the airborne frost-point hygrometer data along with satellite and re-analysis data are presented and the discrepancies are discussed.

CLOUD MICROPHYSICAL AND RADIATIVE PROPERTIES}

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The boundary layer clouds, covering extensive areas of our globe, have a significant impact on the Earth's radiative balance and thus on climate. Parametrization of cloud radiative properties as a function of their microphysical characteristics are needed for retrieval of cloud microphysical parameters from remote sensing measurements and for simulations of aerosol indirect effect (modification of cloud albedo) in GCMs. Usually layer clouds are represented as plan parallel homogeneous horizontally and vertically and their radiative properties are defined by two parameters: optical thickness and effective radius. In reality such clouds are not homogeneous neither horizontally not vertically. In the scale of a convective cell the vertical adiabatic profiles are well documented by in-situ measurements, so it is possible to describe recisely the cloud microphysics and radiative properties by using only two parameters: cloud depth and droplets concentration (what allows to easily describe the indirect effect of aerosols). This result is then averaged in order to get the mean radiative properties of the cloud system. EUCREX (European Cloud Radiation Experiment) and ACE2 (Aerosol Characterization Experiment) were dedicated to in-situ studies of microphysical properties of marine stratocumuli and simultaneous measurements of their radiative properties. The results of these experiments will be presented.

CONVECTIVE MESO-SCALE BOUNDARY LAYER CLOUDS STRUCTURES DURING THE SEMAPHORE CAMPAIGN.

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One of the objectives of the SEMAPHORE campaign is the concern of Ocean-Atmospheric fluxes with the convective activity within the planetary boundary layer. The convective activity is determined from its cloud signature - closed and opened cells, cloud streets - in the AVHRR views of the SEMAPHORE region.
As a first step the cloud classification of Seze-Desbois allows to segregate between low clouds fields and others; moreover, it allows to characterize the cell fields through a bench of specific classes. The second step consists in an algorithmic treatment of the classification output to specify the shape, extension and arrangement of the cells within the low clouds fields. As a consequent, the variability and irregularity of the geometric characteristics of the clouds - which are at the origin of the choice of this method - are thus quantitatively restituted. Finally, the geometric information is used to extract the physical characteristics of each determined elementary object from both the classification outputs and the four-channel AVHRR data. Tus, the charactristics of a mean elementary cell or roll is given which allows future comparison with model outputs.

Cloud type and horizontal variability in marine boundary layers

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Large scale models such as those used for weather prediction and simulations of climate change typically estimate the radiative effects of clouds based on the cloud fraction and total amount of condensate within each grid box. It is known, however, that the assumption that cloud optical properties are horizontally uniform leads to a systematic bias towards larger albedo and smaller absorption. Simple techniques have been developed to account for cloud spatial inhomogeneity in radiation calculations, but observations of this variability are quite sparse.

We use simultaneous co-located observations by ship observers and satellite radiometers to characterize the variability of marine boundary clouds. We examine the sensitivity of cloud detection by satellite instruments to cloud morphological type as reported by the ship observers and to sensor spatial resolution. Observed distributions of cloud optical thickness are well described in most cases by several two-parameter models including log-normal and gamma distributions. The resultant bias in domain averaged albedo over the spatial scales used in current models is relatively small, but it can be nearly eliminated using one of the simple models of variability. The parameters which characterize the distributions are dependent on cloud type, most importantly on whether the clouds are reported as isolated (cumuliform) or nearly continuous (stratiform).

NANOPARTICLE FORMATION EVENTS AT A BOREAL FOREST SITE

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Number size distribution of submicron and ultrafine aerosol particles have been measured on a continuous basis (every 10 minutes) at a forest site in Southern Finland. Very often, only Aitken (40-100 nm) and accumulation modes (150-200nm) are present. In several sunny days, the appearing nucleation mode (peak at 5-6 nm) can be seen to increase both in size and concentration. During the day the growth rate for the nucleation mode is in the order of few nm/hour and at late evening the nucleation mode merges into the Aitken mode. Simultaneous eddy covariance measurements have revealed upward particle fluxes, when there is formation of new particles. Atmospheric significance of observations are discussed.

Cloud cover observed simultaneously from POLDER and METEOSAT

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The POLDER instrument that was aboard the Japanese ADEOS platform between August 1996 and June 1997, is designed to the global observation of the polarization and directionality of the sun-light reflected by the earth atmosphere system. The cloud detection from POLDER takes advantage of the original capabilities of the instrument (spectral polarization and directionality). This cloud scheme uses 5 threshold tests based on pressure, reflectance, polarized reflectance, spectral variability. The results of the POLDER cloud detection scheme are compared to those of the LMD dynamical clustering method applied to visible and infrared METEOSAT data and local spatial variability of these two parameters. Special focus is given to the detection capabilities of the two kind of measurements for cloud situations such as small cumulus, thin cirrus and multi-layered cloud cover. Results of this comparison will give some insight on the behavior of the International Satellite Cloud Climatology (ISCCP) scheme built mainly from visible and infrared measurements.

DIRECT EVIDENCE FOR CLOUD CASCADE DYNAMICS FROM PLANTARY SCALES TO 1KM

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We analyzed over a thousand visible and infra red images from geostationary (GMS), polar orbiting (NOAA 12, 14, SPOT) satellites as well as ground based images (roughly 100 times more data than that used on any comparable study) to study the scaling properties of clouds over the range 5000km to ≈50cm. As predicted by the unified scaling model, the radiances are accurately multiscaling over the entire range and we estimate the corresponding (universal) multifractal exponent functions. Although the individual images involve factors of only ≈1000 in scale (compared to the range of over a billion from the planetary scale to the dissipation scale), these large (climatological scale) data sets enabled us to obtain the first direct estimates of the outer scale of the underlying (multiplicative) cascade process. Both the GMS (over the Pacific) and AVHRR (over Oklahoma) data yield estimates of the order of ten thousand kilometers; an agreement which is particularly convincing in this regard.

We discuss the significance of these results for radiation, climate and modelling.

A SENSITIVITY STUDY OF RADIATIVE-CONVECTIVE EQUILIBRIUM IN THE TROPICS WITH A CONVECTION-RESOLVING MODEL

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Statistical-equilibrium (S-E) states of radiative-convective systems in tropical oceanic conditions are simulated with a cloud ensemble model (CEM) in this study. Typical large-scale conditions from the Marshall Islands and the eastern tropical Atlantic regions are used to drive the CEM.

The simulated statistical-equilibrium precipitable water, column temperature and relative humidity profile are almost identical to the observed for both regions when observed, time-invariant large-scale advective cooling and moistening effects are imposed. They are higher than the observed if observed, time-invariant large-scale ascent is imposed for the Marshall Islands region (i.e., ignoring horizontal advective effects). Compared with results from two similar studies, the simulated S-E state from this study is somewhere between the cold/dry regime by Sui et al. and the warm/humid regime by Grabowski et al. Temporal variations of the imposed large-scale vertical motion make the simulated S-E state slightly colder and drier. It remains about the same, however, if the magnitude of the imposed large-scale vertical motion is halved. The S-E state is much colder and drier if the large-scale ascent is zero or if solar radiation is absent. In general, the results show that wet column are thermally stable and dry columns are thermally unstable.

Column budget analyses are performed to explore the differences among the simulations performed in this study and among the different studies.

TIMESCALES OF VARIABILITY IN TROPICAL RADIATIVE-CONVECTIVE EQUILIBRIUM

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In an undisturbed environment, the tropical atmosphere tends towards a state of radiative-convective equilibrium. The timescale on which this balance is achieved is an important issue. This convective heating and moistening response has been previously suggested, for example, as central to amplification of large-scale wave-motions, and their successful simulation in global models.

To examine internal convective variability, we have integrated a three-dimensional cloud-resolving model with an interactive radiation scheme to a state of radiative-convective equilibrium. Using a model that explicitly resolves convection avoids the timescales assumptions built into parameterizations schemes, but does not allow the two-way interaction between convection and large-scale wave motions to be studied due to the limited domain size.

It is found that the approach to equilibrium can be divided cleanly by a process separation into two timescales; a long 20 day exponential trend to equilibrium superimposed by short timescale variability that is almost solely associated with convective activity. Of the two possible mechanisms of surface fluxes and radiation it is found that the latter determines the long-timescale adjustment.

OA17 Climate variability: models and observations (joint with SE)

05 Prediction and detection of anthropogenic climate change

Convener: Johns, T.C.

GCM CLIMATE CHANGE SCENARIOS FOR BULGARIA

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Climate change scenarios for Bulgaria using global circulation model (GCM) outputs were derived and analyzed. The GCMs used in the study are those from the Canadian Climatic Center (CCC). Goddard Institute for Space Studies (GISS). Oregon State University (OSU). Geophysical Fluid Dynamics Laboratory (GFDL R-30). United Kingdom Meteorological Office (UK89) and Hadley Centre in the United Kingdom (HCGG and HCGS which integrates the negative forcing effect from sulfate aerosols. The GCM simulations regarding the current climate were compared to the averaged database of the observed climate. The GCMs do not perfectly simulate the present climate in Bulgaria. Nevertheless, the $1xCO_2$ OSU, HCGG and HCGS outputs are in a relatively good agreement with baseline air temperature from June to March. They could be considered as the most appropriate global circulation models for monthly air temperature in Bulgaria (except April and May) among the GCMs used in the study. According to the $2xCO_2$ GCM outputs used in the study annual temperatures in Bulgaria are projected to rise between 2.9° (HCGS) and 5.8°C (UKMO). Under the GFDL-T transient scenario in the 2000s, 2030s and 2060s annual temperatures are projected to increase by 1.2°, 2.2° and 3.9°C, respectively. In general, precipitation is expected to increase during the winter and to decrease during the warm half-year(CCC, GISS, GFDL R-30, OSU). The $2xCO_2$ UK89 and HCGS models even project minor increasing only in November and July, respectively.

DETECTING EXTERNAL FORCINGS OF THE ATMOSPHERE USING THE ERA DATA SET

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The European Re-Analysis (ERA) data set provides not only re-analysed observations, but also short range forecasts based on these data. A forecasted field will, of course, deviate from the observed, re-analysed field. Assuming a realistic model and perfect observations, this deviation, also called analysis increment, may in most cases mainly be assigned to instrumental inhomogeneities and external forcings that are not considered by the forecast model. The contribution by instrumental inhomogeneities is assumed to be mainly on a time scale of years. Thus, the analysis increment will, particularly on shorter time scales. provide a measure of external forcings. This paper presents a study of analysis increments of temperature fields at several pressure levels.
Some external forcings such as the strong emissions of sulfate aerosols from the vulcanic eruptions of El Chichón (1982) and Pinatubo (1991) are easily identified, and serve as a good verification of this method. Particular attention is paid to possible forcings originating from solar activities. Both Forbush decreases which has a time scale of days and forcings on the longer time scale of the 10-12 year solar cycle, like the reported influence of cosmic ray flux on cloud cover, has been investigated. Though the results are less conclusive on the longer time scales, this study of temperature fields shows little evidence of forcings induced by such solar activities.

MAIN REGULARITIES OF THE CLIMATE CHANGES OF UKRAINE IN THE PAST

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The was made a critical analysis of materials concerning changes of land-surface temperature, intensity of atmospheric precipitation and statistics of catastrophic hydro-meteorological phenomena on the territory of Ukraine, obtained on the basis of results of meteorological paleo-reconstruction, historical (manuscript) records and instrumental hydro-meteorological observations. There were found general changes regularities of the climate of Ukraine during the last 10 000 years. There were considered conditions, in which the climatic fields of land-surface temperature and the intensity of precipitation, which took place in warm periods of the past, may be analogous for the development of scenarios of Ukrainian climate changes in the near future taking into account forecasted global warming being the result of the anthropogenic increase of the green-house gases effect.
The statistics of catastrophic hydro-meteorological processes (CHMP) is quantified by the well-known relation for Puasson flux of events. There were made estimates of the Puasson flux of CHMP on the territory of Ukraine and there was considered the possibility of their use for forecast of global warming influence on the statistics of CHMP on the territory of Ukraine in the near future.

MEDITERRANEAN SEA: INCREASE IN GREENHOUSE EFFECT, AIR AND SEA TEMPERATURES AND FRESHWATER DEFICIT

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In the deep waters of the western basin, increasing trends of temperature and salinity, observed since the early 1960s (Bethoux and Gentili, 1996), may be simulated by surface evolutions of heat and water budgets across the sea surface, i.e. two concomitant driving forces. Over the 1940-1995 period, the estimated change in greenhouse effect simulating the warming trend reaches 1.74 Wm^{-2}, which is in agreement with the calculated change (GIE, 1995), and sea surface and air temperature increases amount to 0.4 and 0.5°C, respectively. Simulation of salinity trends requires an increase in water deficit of 0.10 m a^{-1} in 1995. This originates in:
i) decreases in Nile river outflow (after the closing of High Dam in 1954), and Ebro river outflow (human freshwater use); ii) increase in salty flow from the Red Sea (following the deepening and widening of the Suez canal); iii) decrease in precipitation over the Mediterranean; iv) increase in evaporation (feedback from the surface temperature increase). Causes are both from anthropogenic and climatic sources. Mediterranean sensitivity to climatic and environmental changes constitutes chances to monitor present changes, if climatic and socio-economic data exist.
Bethoux, J.P. and Gentili, B., 1996. J. of Mar.Systems, 7: 383- 394.
GIEC, 1995. Changements climatiques 1995. PNUE/OMN, pp. 64.

POSSIBLE CHANGES IN EL-NIÑO/SOUTHERN OSCILLATION IN A WARMER CLIMATE

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The El-Niño/Southern Oscillation (ENSO) is examined in the Hadley Centre climate model to asses any future changes in the behaviour of ENSO in a warmer climate. Various simulations, forced with transient increases in CO_2 alone, transient increases in CO_2 and sulphate aerosols, and simulations with equilibrium changes, are compared with a multi-century control run forced with present day CO_2 levels. ENSO indices from the model and from the observations are compared using spectral and wavelet analysis techniques. These measures of ENSO activity are tested for statistical significance against the control integration which is used to estimate a measure of the "natural" variability of ENSO. The preliminary indications are that power in the 2-3 year band of the NINO3 index increases in many of the increased CO_2 simulations. If the model predictions are correct, this implies that ENSOs will become more frequent in a warmer climate.

RESPONSE OF THE NCAR CLIMATE SYSTEM MODEL TO CHANGING GREENHOUSE GASES

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The NCAR Climate System Model (CSM) is a relatively new model of the physical climate system, including coupled atmosphere and ocean general circulation models, a dynamic sea ice model and a land surface model. This paper summarizes results of several CSM experiments in which the concentrations of greenhouse gases change with time. Trends are compared with the natural variability of a 300 year control simulation and with the observed record.
An idealized experiment, following the guidelines for CMIP2, in which CO_2 increased from present levels (355 ppmv) by 1%/year will be discussed. This experiment was run until the CO_2 concentration tripled (115 years) and is compared to a 300 year control simulation. In this experiment, the global mean surface temperature increases by $\sim$ 1.3 K at the time of CO_2 doubling (70 years). The equilibrium temperature increase for CO_2 doubling is $\sim$ 2 K, as determined by experiments with a 50 m slab ocean.
A more realistic series of experiments is currently underway, in which changes in the principal greenhouse gases (CO_2, O_3 CH_4, N_2O, CFC11, and CFC12) and sulphate aerosol from 1870–1990 are included. These experiments begin from an approximate equilibrium condition for 1870 and account for most of the greenhouse gas changes since pre-industrial times.

VARIATIONS IN HEMISPHERIC AIR-SURFACE TEMPERATURE ASSOCIATED WITH LARCE SCALE FLOW PATTERNS

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To what extent the recent upward trend in hemispheric mean surface air temperature should be purely ascribed to persistent circulation-related anomalies, is still an open question. The purpose of this study is to clarify the role played by the internal atmospheric variability in generating hemispheric mean surface air temperature anomalies. To investigate this problem an analysis is performed on a basis of monthly mean values from a 1000-years integration of the ECHAM1-LSG coupled model in which only the cold season was considered. In order to isolate important coupled modes of variability between time series of 500 hPa geopotential height and two metres temperature, a Canonical Correlation Analysis (CCA) was carried out. The two fields were prefiltered by retaining only the projection of each field on a (particular) subset of its Empirical Orthogonal Functions (EOFs) then applying CCA. This analysis has identified fairly distinct patterns associated with positive and negative trends of the hemispheric-mean surface air temperature. It is found that fluctuations in hemispheric-mean surface air temperature in the model are correlated with the strength of the North Atlantic Oscillation. The model results are then compared with the available observations.

QUANTIFYING THE UNCERTAINTIES DUE TO LAND-SURFACE SCHEMES IN CLIMATE CHANGE PREDICTION

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In their 1995 report, the IPCC identified land-surface processes as an area of large uncertainty in predictions of global and regional climate change due to greenhouse gases. The Land Surface Processes and Climate Response project, funded by the European Union, is an attempt to determine the magnitude of this uncertainty through collaboration between modelling centres. In this work four atmospheric general circulation models were used to perform at least two pairs (control and anomaly) of climate simulations. The difference between each pair was a change in some aspect of the land-surface scheme used. The experiments were all time-slices of at least 10 years with the same, specified sea surface temperature and sea ice data. For several regions, statistically significant changes in regional climate can be picked out from model noise, and the differences and similarities across the land-surface schemes and GCMs analysed. For some regions and variables, results for the same GCM with changed land-surface parametrisation cluster together whereas in other regions the difference between land surface schemes equals that between GCMs. In the Amazon basin for example, the difference in climate response between land-surface schemes was similar to that between GCMs.

CIRCULATION MODES AND THEIR INTERDIURNAL VARIABILITY IN THE ECHAM GCM

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The contribution addresses two items: (i) validation of the ECHAM GCM in terms of circulation patterns and their interdiurnal variability, and (ii) potential changes in circulation regime in $2\times CO_2$ climate. Circulation is expressed as a linear combination of Principal Components (PCs) which represent leading modes of variability in 500 hPa geopotential height field. Geopotential data were available in three variants: (i) raw data, (ii) low-passed data (to filter out high-frequency variations) and (iii) band-passed data (to retain synoptic-time-scale variations). PCs were derived separately for the 4 seasons of the year, from a) observed data, b) GCM (ECHAM3/T42) control run (present climate), and c) GCM/$2\times CO_2$ run. Comparison of circulation modes (spatial patterns of PC loadings) and their interdiurnal variability (represented by lag-1 correlations among PC scores) derived from individual data sets shows: (i) the circulation modes are well reproduced in GCM/control run, (ii) good correspondence between GCM/control and GCM/$2\times CO_2$ modes suggest only small changes in circulation regime over Europe due to doubled CO_2, (iii) the GCM/control circulation is more persistent (compared to observation) and closer to GCM/$2\times CO_2$ than to observation.

THE EFFECT OF UNCERTAINTIES IN RADIATIVE FORCING ON SURFACE TEMPERATURE TREND PREDICTIONS

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This paper examines the range of uncertainty in our knowledge of the anthropogenic and natural radiative forcings since 1850. Simple climate models and an Intermediate General Circulation Model (IGCM) are used to crudely examine the likely effect of these forcings on the surface temperature trend. It is concluded from these experiments that any agreement between time-dependent global-mean surface temperature trends and surface temperature trends from GCM runs, which include only a few of these forcings, are probably only fortuitous, and as such the evolution of surface temperature in these experiments to not constitute a "detection of anthropogenic climate change".

Changes in extreme daily precipitation predicted by general circulation models under scenarios of increased CO2 concentration

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A change in the intensity and distribution of daily precipitation towards more extreme events in certain areas is predicted by Hadley Centre general circulation models (GC-Ms) in greenhouse gas (GHG) emission scenarios. This shift could have significant consequences, resulting in floods, for instance, in some areas. In this study, changes in precipitation intensity are characterised by appeal to the probability density functions of daily precipitation amounts at each location, because it may be more instructive to define extreme events in terms of geographically dependent probabilities, rather than fixed value thresholds. We also compare the GCM results for changes in extreme events over Europe with corresponding results from a limited area model, the Hadley Centre Regional Climate Model.

REGIONAL IMPACTS OF THE VEGETATION FEEDBACKS IN DOUBLED-CO_2 CLIMATE EXPERIMENTS

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Three 10-year doubled CO_2 experiments have been performed with the ARPEGE atmospheric general circulation model of Météo-France in order to investigate how the CO_2 impact may be affected by possible vegetation feedbacks. Besides a first time-slice experiment with no modification of the vegetation properties, two other experiments have been performed in which changes in the plants' physiology (stomatal resistance) and structure (vertical density of the canopy) have been explored. On global and annual average, the vegetation feedbacks do not much modify the model's response to the CO_2 doubling. On the regional scale, the effect may be much more significant, which is demonstrated through the example of the Indian summer monsoon. Despite the increased land-sea temperature contrast, the monsoon circulation and precipitation are weaker in the first time-slice experiment, due to a competition between convection over the Indian continent and the Indian Ocean. This impact successively disappears and reappears when the physiological and structural feedbacks of the terrestrial vegetation are considered. This result shows the need for including more interactive land surface schemes in climate models, in order to capture all the processes involved in the carbon and water cycles.

CLIMATE CHANGE DUE TO A CO_2 INCREASE AS SIMULATED BY THE IPSL COUPLED MODEL

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The IPSL coupled model has been used for two eighty-year simulations: a control simulation with constant CO_2 concentration and a scenario simulation with a 1% yearly increase in CO_2 concentration. The absence of any flux corrections implies that an initial drift, which stays reasonable, is present in the two simulations. The general characteristics of the control simulation will be presented as well as the perturbations on the atmospheric and oceanic circulations due to the CO_2 increase and particularly the SST perturbation which is peculiarly strong along the equator in the Pacific. Comparisons with similar experiments using a simple oceanic mixed layer as the oceanic component of the coupled model will be made to illustrate the part of oceanic circulation in the perturbed simulations.

A STUDY FOR THE IDENTIFICATION OF CO_2 SOURCE AREAS.

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We present a study concerning the distribution of CO_2 atmospheric concentration and its possible sources on synoptic scale. The used method is the following:
a) we have measured the continuous concentration of CO_2 concentration at the alpine station of Plateau Rosa
b) we have calculated backwards trajectories of air crossing the monitoring station every 6 hours. For the trajectory calculation we have used the wind speed fields provided by the ECMWF objective analysis.
c) we have calculated the medium field of CO_2 concentration on European area following what was suggested by A. Stohl (Trajectory Statistics-A new method to establish source-receptor relationships of air polluttants and its application to the transport of particulate sulfate in Europe, Atmospheric Environment, vol.30, n.4, 1996)
The described procedure is applied to the data period April 1993- March 1995.
The results are presented and discussed.

NONPARAMETRIC TEST OF AR ORDER WITH APPLICATION TO THE GCM-SIMULATED AND MEASURED AIR TEMPERATURES

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Estimate of the impacts of climate change on agriculture, water resource management etc. requires high resolution (in space and time) air temperature data. Since the output from general circulation models (GCMs) is frequently unreliable at the local scale, alternative method to obtain such data is to use a stochastic weather generator, which employs an autoregressive model to simulate the daily extreme air temperatures. New nonparametric tests of the order of the autoregression in the time series, based on autoregression rank scores, were recently developed by Hallin and Jureckova, 1997. These tests and order identification procedure will be applied to a 30 years dataset of daily extreme temperatures in south Moravia (Czech Republic) over the period of 1961-1990 and to daily temperature series simulated by GCMs for $1xCO_2$ and $2xCO_2$ climate.

SIGNIFICANCE OF ROOTING DEPTH ON CLIMATE CHANGE PREDICTION

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The IPCC report predicts increased summer drying in the Northern Hemisphere in an enhanced greenhouse climate. This of major significance as it affects a major agricultural belt as well as many other land areas. One factor determining the vegetation stress is the total water availability, which is closely related to the rooting depth. However there is currently limited biome rooting depth data available and it is generally not directly applicable to GCMs.
As part of the *Land Surface Processes and Climate Response* collaborative project, the ECMWF's (European Centre for Medium-Range Weather Forecasts) IFS GCM (version 15r1) is used to carry out a number of $2xCO_2$ simulations. The SST fields are prescribed and based on climatology, with adjustments made for $2xCO_2$ conditions. Experiments are performed with a range of globally uniform rooting depths which are chosen to cover most of the observed variation. Finally a geographically varying rooting depth field is developed and tested. The importance of rooting depth is assessed, both in terms of the accuracy of the present day simulation and on its effect on climate change sensitivity.

WHETHER THE GLOBAL WARMING CAN BE AVOIDED ACCORDING TO THE "IRON THEORY" OF DR. J. MARTIN?

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On the basis of the data obtained by instrumental measurements carried out by our research group in the open sea and laboratory it was shown that it is impossible to stop warming of the climate as predicted by the "iron theory" of Dr. J. Martin. The idea was that phytoplankton in the ocean needs iron and if the ocean were "fertilized" with iron compounds, the growth rate and abundance of phytoplankton would increase. This would lead to fixing CO_2 dissolved in sea water in the process of photosynthesis and, consequently, to reduction of air emissions of CO_2. In the course of the experiment a 65-km^2 patch of the equatorial Pacific 1600 km west of Ecuador coast was fertilized by sprinkling 450 kg of iron sulfate from a ship. This yielded 500 ton of phytoplankton and the emission of carbon dioxide from the ocean was reduced by 60%. Thus, it seemed that the experimental results fully confirmed the "iron theory" and provided a way to reduce the greenhouse effect.

However, the results of the "iron theory" should be treated with caution due to the fact that the experiment did not take into consideration other possible processes which accompany induced growth of phytoplankton. Incidentally, growth of biomass in the ocean would undoubtedly cause clouding of sea water and, hence, transformation of the absorbed solar radiation into heat. As a result the emission of water vapor into the atmosphere, increases, which leads to enhancement of the greenhouse effect.

THE INFLUENCE OF GLOBAL WARMING ON THE LEVEL OF THE BLACK AND AZOV SEAS

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There was made the statistical analysis of instrumental measurements of Black and Azov seas' levels during the last 100 years. The results were compared with the instrumental data on the state of land-surface temperature of the North Hemisphere and also with the own increase of the World Ocean level. All numbers are well correlating (correlation coefficients, for example, between the changes of average temperature and the level of the Black sea is 0,57, and between the changes of the levels of the Black and Azov seas – 0,72) and have the tendencies to increase on the background of low-frequency fluctuations, which is the evidence of the influence of global warming on the level of not only the World Ocean as a whole but also internal seas. It was found that Black and Azov seas are reacting quickly enough on the temperature changes and can, in some sense, be climate indicators. The results were used for forecasting the changes of the level of the Black and Azov seas in the near future.

TREND ESTIMATES FROM US ROCKETSONDE STATIONS AT LOW LATITUDES (8°S-34°N), TAKING INTO ACCOUNT INSTRUMENTAL CHANGES AND NATURAL VARIABILITY.

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Long-term changes of temperature and wind data obtained with US rocketsondes at 6 selected sites at Northern tropical and subtropical locations (from 8°S to 34°N) have been investigated. The analysis method used here is based on a multi-functions regression analysis that takes account for a continuous linear trend, for natural variability, as well as sudden change of the mean due to successive instrumental improvements. Changes in the time of measurement may also impact on trend estimates due to tidal effects. This effect is probably enhanced by the direct solar radiative heating on the sensor. Using this analysis, a significant cooling of 1 to 3 K/decade, increasing with height (20-60 km) is detected in the upper stratosphere. A similar analysis on zonal wind data reveals no significant trends larger than 0.5 m/s/year.

ON THE ENERGY RELATED CLIMATE VARIABILITY

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The importance of interaction between climate as one of the main natural systems and energy as a major sector in the economy defines the necessity to study this interaction in deep. The paper presents results from such a study focused on the energy related climate variability. The study aims to describe and quantify relations between the energy related Greenhouse Gas emissions, CO2 and NOx in particular, and some basic climatic characteristics like average temperatures at regional scale. The analysis within the study is performed in the framework of the concept for the differences between the global and regional pattern of the climate system behaviour. On the other hand, predictions for the future state of this system are mostly necessary at regional scale for the development of relevant energy policy for a country or region. The study provides basis to formulate principles for the development of such a policy in order to support decision-makers.

ASSESSEMENT OF FUTURE TEMPERATURE OF UZBEKISTAN AS RESPONSE TO GLOBAL WARMING

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For the assessment of the future change of the temperature regime of Uzbekistn as the response to global warming and taking into account regional natural variability the statistical-probabilistic approach is used. The significant statistical relation between the annual air temperature at the areas of Uzbekistan and global temperature are established. On the base of these statistical relations the possible change of annual regional air temperature and winter spring, summer and autumn temperature are calculeted using the model assessment of the global temperature for different emission scenarios

Due to high natural variability the regional climate forecasts are given in the probabilistic form, i.e. to accompany with an information about the uncertainties It is recognised that the variations of the air temperature of Uzbekistan are related to the solar 22 year magnetic cycle Therefore, to reduce the range of uncertainty in regional climate forecasts bi-decadal natural oscillation is used

Testing procedure on the independent control series 1990-1996 shows a good quality of the Uzbekistan climate change assessment.

Sea Level Rise: HadCM2 Model Predictions

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Observations indicate that the global mean sea level has risen at a rate of approximately 1.8 mm yr1 during the past century. Furthermore, modelling studies suggest that increased atmospheric concentrations of greenhouse gases will result in an increased rate of sea level rise in the future. In this work, both the global mean and the spatial pattern of sea level rise predicted by the HadCM2 model are presented. The spatial pattern of sea level rise is shown to be spatially inhomogeneous with a range that is of the same order of magnitude as the global mean sea level rise associated with thermal expansion. The pattern of sea level rise determined from the change in the model's inferred sea surface height is compared with the patterns of: heat uptake by the ocean, thermal expansion deduced from changes in modelled ocean temperature structure, and changes in surface wind stress and atmospheric pressure. In addition, the depth and spatial variation of the terms in the Navier Stokes equation are considered in order to elucidate the changes in ocean circulation that are concomitant with the sea level rise.

ESTIMATING CLIMATE TRENDS BY NONPARAMETRIC REGRESSION

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Trend analysis of climatological time series has an important role in description of climatic changes. A general model for time series $y_0, y_1, \ldots, y_n$, is $y_j = f(t_j) + e_j$, $j=0,1,\ldots,n$ where $f(t)$ is a deterministic function called trend function which has to be estimated and $\{e_j\}$ is a sequence of uncorrelated random variables with zero expectation. Knowing the analytical form of $f(t)$ the estimation is straightforward. Unfortunately, the typical case is that form is not known and therefore a model is chosen for $f(t)$. Nonparametric regression methods, which do not require the choice, represent estimators unbiased up to kth derivative of the trend function defined by a local kth order polynomial approximation of $f(t)$. The problem results in a weighted linear combination, i.e., smoothing of the observations $\{y_j\}$. The question is how to choose smoothing weights and range of smoothing (bandwidth). The presentation discusses these problems, as well as the advantage of locally varying bandwidth. Methodologies concerning the choice of bandwidth will be applied to a Northern Hemispheric temperature anomaly data set.

A TIME-SLICE EXPERIMENT WITH THE ECHAM4 A-GCM AT ENHANCED RESOLUTION: FIRST RESULTS

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A time-slice experiment has been performed employing the ECHAM4 A-GCM at a horizontal resolution of T106 with each time-slice covering a period of 30 years. The first time-slice represents the present day climate and the second one the climate at a time, when the CO_2 concentration in the atmosphere has doubled. In these time-slices the atmosphere has been forced by lower boundary files, that are monthly mean values of the sea surface temperatures, the sea-ice extent and the sea-ice thickness. obtained from a transient simulation with the ECHAM4/OPYC A-O-GCM at a horizontal resolution of T42, where the concentrations of the important greenhouse gases had been prescribed according to the IPCC scenario 1992a. We present results showing the anticipated change in the general circulation due to a doubling of the CO_2 concentration in the atmosphere as derived from these time-slices. This includes seasonal mean fields of various meteorological variables as well as variations on sub-seasonal timescales.

PERFORMANCE OF CURRENT CLIMATE-MIDDLE ATMOSPHERE MODELS: RESULTS FROM THE GRIPS INITIATIVE

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Current interest in the middle atmospheric effects on climate motivated the formation of the SPARC (Stratospheric Processes and their Role in Climate) project of the World Climate Research Programme. One initiative of SPARC is designed to assess the performance of current climate-middle atmosphere models; thirteen models are presently included, all of which include a full representation of the hydrological cycle and radiative processes and extend upwards to at least 1 hPa.

One of the first exercises of the GCM-Reality Intercomparison Project for SPARC (GRIPS) is an assessment of the models simulation of the current climate. This gives a background for planned sets of experiments, which will investigate how well the effects of middle atmospheric change on climate can be predicted.

The present paper will discuss results of GRIPS, first concentrating on the simulated structure in the lower stratosphere and upper troposphere. The importance of the reference climatology will be emphasised. The second focus of the presentation will be on the structure of the mean standing waves in the troposphere and stratosphere in the Northern Winter. These two issues have tremendous implications for current and future climate simulations.

TESTING FOR GLOBAL WARMING AGAINST STATIONARY NATURAL CLIMATE VARIABILITY

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Several papers have considered whether the mean global temperature record is statistically significant relative to the warming trend possible due to the natural variability of the climate system. However, previous work is not definitive due to the qualitative nature of the results and/or the use of a single General Circulation Model run as representative of the natural climate variability. I show that the natural variability of the system, as represented by pre-Industrial time series of atmospheric temperature variations, is statistically stationary and the autocorrelation of the time series is determined. Model global and regional time series statistically identical to those observed are then generated in monte carlo simulations to quantitatively determine the likelihood that the mean global warming and regional warming trends are statistically significant relative to the natural variability. Both the global and regional warming trends are found to be entirely consistent with natural variability.

THE IMPACT OF A COMPLEX LAND-SURFACE SCHEME ON THE RESULTS OF A CLIMATE CHANGE SIMULATION

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Most climate change experiments have been carried out with GCMs coupled to simple land-surface schemes. In this study, the impact of upgrading to a complex land surface on the simulated climate change will be analysed.
Within the project "Land-surface processes and climate response" two time-slice experiments for a climate with enhanced CO_2 concentration have been carried out. The oceanic surface conditions produced by the Hadley-Centre were used. The first time-slice was performed with the standard BUCKET scheme, which has been in use in most GCMs, the second one uses the complex scheme SECHIBA, which includes an explicit representation of the canopy. The impact on the hydrological cycle over continents in a changed climate will be the focus of the analysis.
A third time-slice experiment will be performed in which the surface conductance will be changed to represent the response of the vegetation to a CO_2 enriched environment. This effect will be compared to that of the change in land-surface schemes.

COMPARISON OF ATMOSPHERE MODEL AND COUPLED MODEL CLIMATE CHANGE DETECTION ESTIMATES.

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We show a new approach to climate change detection and attribution using an atmospheric general circulation model (AGCM). Ensembles of AGCM runs were forced with the observed history of sea surface temperature (SST) and sea ice extent and a variety of forcing factors added incrementally.
We compare these runs from those from coupled model (CGCM) runs forced with the same changing anthropogenic forcings. The AGCM detects a signal that is additional to any feedbacks between the anthropogenic forcing and the ocean. We show that the "residual" anthropogenic signal in the AGCM is not much smaller than the CGCM signal. For zonally averaged vertical profiles of temperature, the AGCM internal variability is on average substantially less than that of the CGCM. Thus we detect anthropogenic influences at a clearly statistically significant level in the troposphere and lower stratosphere.
However, only a CGCM can simulate the full impact of anthropogenic forcing on the climate, so the AGCM provides a complementary detection and analysis method. Accordingly, the Hadley Centre has now started parallel runs of an AGCM and a CGCM with the same time-varying forcings, where the CGCM has the same atmospheric component.

SIMULATED CHANGES IN BAROCLINIC WAVE ACTIVITY OVER THE ATLANTIC: A NAO VARIABILITY EFFECT?

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In accordance with a number of other GCM experiments, the coupled ocean–atmosphere GCM ECHAM4(T42, L19) + OPYC3 simulates an increased upper air stormtrack activity (bandpass filtered 500 hPa geopotential height variability) over the East Atlantic and Western Europe with increasing CO_2 forcing. A consistent signal is also found in the distribution of surface cyclones. While the deepest cyclones are located over the central Atlantic for all CO_2 forcings considered, the cyclone depth distribution is shifted towards lower core pressures over the East Atlantic and European sector. Previous observational studies link such a distribution also with the variability of the North Atlantic Oscillation (NAO). It turns out that the anthropogenic change in baroclinic wave activity cannot be regarded as an artefact of the particular dominating NAO phases during the simulation episodes considered. Although the signal to noise ratio is rather low, there are indications of a systematic change towards higher mean NAO index values with increasing greenhouse gas concentrations.

INTERPRETATION OF WINTER WARMING AT NORTHERN HEMISPHERE CONTINENTS IN 1977-1994

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Northern Hemisphere December-March near-surface temperature and pressure anomalies of 1977-1994 relatively to 1946-1976 are considered. These anomalies can be decompose into two almost orthogonal components. The first one reaches its maximum in 1977-1988. Main features of anomalies of 1977-1988 can be obtained as the atmosphere general circulation model (AGCM) response to sea surface temperature anomalies observed in 1977-1988. The second component reaches its maximum in 1989-1994. Main features of anomalies of 1989-1994 relative to 1977-1988 can be obtained as the AGCM response to low stratosphere ozone depletion observed in 1989-1994.
Model response to low-stratosphere ozone depletion was studied. It was shown that it almost coincides with the dominant mode of model low-frequency variability. The same is true for the observed anomalies of 1989-1994. Additional AGCM runs showed that large response to a small low-stratosphere external forcing can be obtained if the external forcing (in our case anomalous zonal mean radiative heating) is spatially correlated with the spatial structure of zonal mean vertical movement associated with the dominant mode. This condition is satisfied for observed low-frequency variability and low-stratosphere ozone depletion. So, real atmosphere can be strongly sensitive to small variations of the ozone in low stratosphere.

SEMI-EMPIRICAL MODELS OF AGE TRANSFORMATION OF THE CLIMATE OF UKRAINE FOR MODERN ERA

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**There were obtained semi-empirical models of climatic fields of the following characteristics of the climate of Ukraine: meteorological norms (average for the period 1961-1990), dispersion from year to year and coefficient of linear trend (period 1900-1990) land-surface temperatures and intensity of atmospheric precipitation. The models are based on representation of time dependency of the mentioned climatic characteristics in form of three items (annual component and two harmonic components) and approximation of the dependency from geographical co-ordinates by linear polynomials.
It was found that changeability of land-surface temperatures from year to year is approximated by normal (Gauss) distribution. There was considered the statistic hypothesis regarding the choice of the approximation scheme of changeability distribution of atmospheric precipitation intensity on the basis of gamma-distribution or log-normal (log-Gauss) distribution. There was made an analysis of possible physical causes responsible for formation of received particularities of age transformation of land-surface temperature climatic fields and intensity of precipitation in Ukraine (decrease of summer temperature in south-west regions of Ukraine, decrease of annual intensity of precipitation in north-west regions).**

ST14 Solar imprints in terrestrial archives (co-sponsored by OA)

Convener: Cini-Castagnoli, G.

RESULTS OF CYCLOGRAM ANALYSIS OF EL NIÑO OCCURRENCES TO SEARCH FOR POSSIBLE PHASE RELATIONSHIP WITH SOLAR ACTIVITY

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The cyclogram analysis has been applied to the dates of El Niño occurrences as reported by Quinn et al.(W.H. Quinn. V.T. Neal, S.E. Antunez De Maiolo, El Niño Occurrences Over the Past Four and a Half Centuries, J.G.R., 92, 14449-14461, 1987). The results will be discussed. This new kind of analysis can detect possible phase relationships of El Niño occurrences and a possible relationships with solar activity cycles or some other geophysical oscillating phenomena, including possible phase locking among them.

LATITUDE DISTRIBUTION OF SOLAR RADIATION INTENSITY FALLING ON THE EARTH'S ATMOSPHERE

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Effect of the secular variations of earth's axis inclination,earth's orbit eccentricity and vernal equinox anomaly on latitude distribution of solar radiation mean intensity is investigated. Different combinations of these parameters change shapes of phase trajectories of annual latitude movement of maximum insolation mean intensity.These trajectories being distributed between the Tropic of Cancer and the Tropic of Capricorn are degenerated into the lines during glacial and heating periods.

THE BASIC 180-YR AND 2200-YR CYCLES IN THE SOLAR MOTION

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On the time interval long 9000 years, the 2200-yr modulation of the basic 180-yr period of solar inertial motion will be demonstrated. (The Sun returns on the trefoil orbital type always after 179 years. In the intermediate intervals, the Sun moves along different chaotic orbital patterns and these intervals coincide with the known prolonged minima of solar activity, such as the Sporer, Maunder, Dalton, etc. minima.) The 2200-years modulation has been detected in two ways: the first consists in a repetition of the intervals long about 400 years, where the Sun exceptionally moves along the trefoil orbital pattern. The second follows from the coincidence between the Sporer and Maunder orbital patterns and the respective Sporer and Maunder types of prolonged minima of solar activity. The trefoil orbit is a repeating, exceptional and stable pattern in solar motion. The same properties of the solar-terrestrial phenomena have been found there. The solar motion, separated into two basic orbital types, could serve as a basis against which solar imprints in terrestrial archives could be related.

RECONSTRUCTION OF THE SOLAR ACTIVITY BASED ON THE ANALYSIS OF COSMOGENIC RADIONUCLIDES IN ICE CORES

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Solar activity modulates the flux of the galactic cosmic rays through magnetic fields carried by the solar wind. This modulation effect has been calculated as a function of geomagnetic latitude and solar activity using Monte Carlo simulations of the interaction between cosmic ray particles with the atmosphere. Records of cosmogenic radionuclides measured in ice cores allow to derive the corresponding modulation factor and to reconstruct the history of solar activity over the last several centuries.

SOLAR VARIABILITY IMPRINTED IN THE $\delta^{18}O$ TIME SERIES OF A SHALLOW WATER MEDITERRANEAN CORE

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The $\delta^{18}O$ profile *of Globigerinoides Ruber* was measured in a shallow water core of the Ionian sea over the period 1200 - 1900 A.D., with the fine resolution of 3.87 years. An accurate dating of the core has been performed by ^{210}Pb radiometric method and by a detailed tephroanalysis. The markers of the historical volcanic eruptions which occurred in the Campanian area (Vesuvius, Phlegrean Fields, Ischia) during the last two millennia have been identified along the cores. The high precision of the core dating allows to transform the depth scale into a time scale with an accuracy of ~1%. The analysis of several cores taken in the same area demonstrates that the results presented here are of general validity, at least in this region. The spectral analysis of the $\delta^{18}O$ time series with different methods show that the dominant periodicity corresponds to 11.4 years; in particular the Singular Spectrum Analysis (SSA) shows: a) the first two leading components (RC 1-2) of the record correspond to a deterministic signals with period 11.4 y in phase with the sunspot record and with an average amplitude of 0.08 per mil. The statistical significance is given by Monte Carlo SSA (MC-SSA). b) The trend (RC 3-4) shows a minimum (warm) in 1400 A.D. and maximum (cold) in 1700 A.D., corresponding to the well-known climatic feature of the Little Ice Age. c) The 22 y running mean of the sunspot record and of the $\delta^{18}O$ time series show the same behaviour from 1700 to 1850 A.D. From there on, the $\delta^{18}O$ time series records the temperature effect due to the CO_2 antropogenic increase.

INVESTIGATION OF THE REFILLING PROCESSES OF CONVECTED PLASMA TUBES ON THE BASIS OF HYDRODYNAMICAL MODEL OF PROTONOSPHERE IN 8-MOMENT APPROXIMATION

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The distributions of concentration Ni and temperature Ti of H+ ions in plasma tube, convected from polar cap to L=6,1 at night, dawn and day side, as well as to L=8,1 at dusk side are presented. They are obtained with help of simplified numerical model of protonosphere based on the set of quasi-hyd- rodynamical transport equations of H+ ions in 8-moment approximation. The integration of model equations is executed along dipole geomagnetic field lines between their bases selected on height of 3000 km. There is assumed, that geomagnetic field lines of polar caps are open. There is taken into ac- count that during magnetospheric convection of plasma tubes the change of their volumes happens. Parameters of steady-state polar wind are chosen as initial conditions for all tubes. The investigation of effects of plasma tube adiabatic compression and expansion in consequence of magnetospheric convection is performed. The distributions of Ni and Ti in meridional planes conformed to 00, 06, 12 and 18 MLT on various heights in protonosphere and in equatorial plane of magnetosphere are obtained. The heating of H+ ions (up to 100000 K) behind the plasmapause, qualitatively agreeing with observations of hot zone in plasmasphere is obtained. This heating is reproduced thanking to addition of the model set by ion heat flux equation.

EARTH'S CLOUD COVER AND COSMIC RAY FLUX VARIATIONS

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A recent result indicates that the Earth's cloud cover, observed by satellites, is strongly correlated with the cosmic ray flux, which in turn is inversely correlated with the solar activity[1]. Since clouds are very important in the radiation budget of the Earth, an influence via cosmic ray flux will have significant climatic effects. For example during the last solar cycle the total cloud cover varied with approximately 3 - 4 % which could correspond to a variation of 1.5 Wm^{-2} during this period. In the talk we will present results on the variations of cosmic ray flux and cloud types and show spatial correlation patterns. An estimate of the importance of different solar activity parameters like, solar radiation, ultra-violet radiation, X-ray radiation, 10.7 cm solar flux, and cosmic ray flux, will be made on the basis of observations of surface temperature on time scales ranging from years to centuries. The results could provide a explanation of the correlation between solar cycle length and global temperature.

[1] H. Svensmark and E. Friis-Christensen, J. atm. sol.-terr. Phys., 59, 1225 (1997)

SOLAR WIND VARIATIONS AND TERRESTRIAL RESPONSES

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The solar wind intensity varies with the sunspot activity. It is well recorded that this modulates the Earth's geomagnetic shielding so that the infall of cosmic ray varies, by that affecting the formation of atmospheric ^{14}C. At the same time it seems to affect the Earth's rate of rotation. During the periods of low sunspot numbers – the Spörer, Maunder and Dalton minima – Earth's rate of rotation increased. This affected the oceanic circulation so that the a major current like the Gulf Stream sent less warm equatorial water along its northern branch towards NW Europe at the same time as Arctic water penetrated furter south. This led to severe cold periods – known as Littele Ice Ages – in the NW European region. In southern Europe and northern Africa the same periods were characterized by increased heat. This means that these periods represent changed distribution of the terrestrial energy. And this was driven by increased rate of rotation. In this scenario, we do not need to call for hypothetical large-scale variations in solar irradiance; only an influence of the solar wind variability on Earth's rate of rotation. There are physical means of understanding the linkage between solar wind intensity and Earth's rotation.

OA18 Heterogeneous and homogeneous chemistry of reactive halogen compounds in the lower troposphere (co-sponsored by ST)

Convener: Platt, U.
Co-Convener: Moortgat, G.K.

ACTIVATION OF HALOGENS VIA HOBr IN THE MARINE BOUNDARY LAYER - A LABORATORY STUDY

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Halogen activation, via uptake of HOBr on seaspray aerosol, is of great interest for the chemistry of the remote- and polar- marine boundary layer. Photochemically active species can be produced according to the following reaction scheme:

$$HOBr(aq) + Cl^- + H^+ \longrightarrow BrCl(aq) + H_2O$$

The BrCl product can (1) diffuse to the gas/liquid interface and enter the gas phase, where it photodissociates, (2) hydrolyse back to HOBr or (3) react with Br^- to form Br_2, which, in turn, may enter the gas phase.

$$BrCl(aq) + Br^- \longrightarrow Br_2(aq) + Cl^-$$

The efficiency (both relative and absolute) of conversion of HOBr to Br_2 and BrCl, depends on the chloride and bromide concentrations in the seasalt aerosol and on the aerosol pH. Laboratory experiments to investigate the interaction of HOBr with sythetic seasalt solutions were carried out using a wetted wall flow reactor / mass spectrometer combination. The results indicate that HOBr uptake onto aerosols with Br^-/Cl^- ratios encountered in the MBL results in predominately Br_2 production. The aqueous chemistry of the system studied was modelled using known equilibrium constants. The results showed excellent agreement with the experimental data.

MEASUREMENTS OF TROPOSPHERIC IODINE OXIDE IN THE MID-LATITUDES

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The role of reactive halogen species (RHS) in stratospheric ozone chemistry is well known today. The discovery of sudden tropospheric ozone depletion events in arctic spring, which were correlated with elevated bromine levels, woke the interest in tropospheric chemistry of halogens and halogen containing species. Following the measurements of Bromine Oxide in the Arctic in 95/96 the question arouse if there may be similar processes at mid-latidudes.
A field campaign in Mace Head / Ireland was carried out in the framework of the HALOTROP / ACSOE projects in April / Mai 1997. We present measurements of O_3, NO_2, SO_2, HCHO, HONO, BrO, ClO and IO by Differential Optical Absroption Spectroscopy (DOAS).
No spectral absorption of BrO or ClO could be identified during the campaign thus the concentration of BrO and ClO were below the detection limit. For the first time, however, it was possible to detect IO in the free troposphere. The characteristic absorption bands of IO between 427.6 nm and 436.4 nm could be identified during several days. The maximum IO concentration was 6.6 ppt (at a detection limit of 1.65 ppt). A calculation of the expected ozone loss with the measured IO concentration will be shown, also possible sources of IO will be discussed.

CHLORINE AND BROMINE DETECTION DURING ARCTIC OZONE DEPLETION EVENTS AT NY ALESUND.

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Reevaluation of the signals from the peroxy radical chemical amplifier, ROx-Box, obtained at the EC-sponsored Arctic Tropospheric Ozone Chemistry (ARCTOC) project revealed this instrument to be sensitive for Cl/ClO as well. During sunny periods the chemical amplifier signals often represent composites of peroxy radicals as well as Cl/ClO. The ROx-Box was calibrated in the following for active chlorine and the amplification mechanism was evaluated.
A few ppt of active chlorine appeared in boundary air ozone depletion events together with bromine oxide as followed by differential optical absorption spectroscopy (DOAS). Apparently both halogens were actively involved in ozone depletion during the campaigns at Ny Alesund, Spitsbergen, in April 1995 and 1996. The discussion will concentrate on the synergy of ozone destruction by bromine and chlorine and will be described by a chemical box model. The results for chlorine bring new insight in the mechanism of halogen release into polar boundary air.

A NEW LABORATORY APPROACH TO HETEROGENEOUS HALOGEN CHEMISTRY

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Dramatic ozone depletion in the Arctic boundary layer has been attributed to the presence of bromine radicals formed via heterogeneous reactions with the aerosol of the remote marine boundary layer. Presently the influence of bromine heterogeneous chemistry on the ozone budget of the less remote, more polluted boundary layer is being discussed. The new project started at Paul Scherrer Institute aims at quantifying the relevant reactions on tropospheric aerosol particles in the laboratory by making use of short lived radioactive isotopes ($^{86,87}Br$) with a half-life of 1 min. Such experiments basically allow the interaction of gaseous molecules with surfaces to be studied at arbitrarily low concentration. In a preliminary study the approach was successfully applied to a model system, namely by studying adsorption and desorption of HI to silver particles. The experiments showed that the interaction of the molecules with the particle surface can be described by an activated chemisorption process determining the low sticking coefficient of HI on silver. In a first application, the desorption of HBr from soot particles was studied to determine the binding energy of HBr to these particles. A broad distribution of chemically different adsorption sites for HBr on soot was derived from these measurements.

AN OVERVIEW OF OBSERVATIONS RELATED TO POLAR TROPOSPHERIC OZONE DEPLETION CHEMISTRY

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In the lower troposphere of the polar regions at sunrise, ozone depletion occurs. It is driven by halogen compounds, particularly those of Br and Cl. Evidence suggests that the source of these halogens are heterogeneous reactions that mobilize sea salt halogens in surface ice and snow. Since the early 1980s when tropospheric ozone depletion was first observed in the Arctic, there have been numerous observational studies of this phenomenon. The most recent have been a series of Polar Sunrise Experiments (PSE) at Alert Canada and the European ARCtic Tropospheric Ozone Chemistry (ARCTOC) project at Ny Ålesund/Spitsbergen. Other recent measurments indicate that tropospheric ozone depletion also occurs in Antarctica. Observational evidence of ozone depletion and related halogen chemistry is reviewed in this paper. In addition, a recently discovered link between the atmospheric cycle of mercury and arctic ozone depletion chemistry is explored.

C_2-C_7 hydrocarbon concentrations in Arctic snowpack interstitial air

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For the first time, samples of interstitial air from within the snowpack on an ice floe on the Arctic Ocean were collected during the 1994 Polar Sunrise Experiment. The concentrations of C_2-C_7 hydrocarbons were determined in Arctic snowpack interstitial air. Hydrocarbon concentrations tended to be higher than concentrations in free air samples above the snowpack, but ethyne concentrations in both interstitial and free air were highly correlated with ozone mixing ratios, consistent with previous demonstrations of the effects of Br atom chemistry. Results were inconclusive due to the limited number of samples, but suggested that there may be some differences in the chemical reactions occurring in interstitial air compared to the boundary layer. In this paper, we will compare air and interstitial samples and will discuss the potential chemical reactions involved in the snowpack and in the gas-phase.

GAS-PHASE KINETICS AND PHOTOCHEMISTRY OF BROMINE AND IODINE CONTAINING SPECIES IN THE MARINE BOUNDARY LAYER

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Recent field measurements have shown that reactive halogen species are ubiquitous to the marine boundary layer (MBL). A central role for bromine (Br, BrO and HOBr, Br_2 and BrCl) has been invoked to explain the well documented episodic depletion of ozone in the Arctic lower troposphere. In addition, measurements of photolabile iodine containing organics such as CH_2I_2 or C_3H_7I and the IO radical indicate that iodine may also play a crucial role in the ozone budget of the MBL. In the present study we present experimental, laser-based kinetic and photochemical results for the following processes:

$$HOBr + h\nu \rightarrow OH + Br$$
$$BrO + DMS \rightarrow \text{products}$$
$$HOI + h\nu \rightarrow OH + I$$
$$HI + h\nu \rightarrow H + I$$
$$OH + HI \rightarrow H_2O + I$$
$$OH + C_3H_7I \rightarrow \text{Products}$$

REACTIONS OF BROMINE ATOMS WITH ALKENES: KINETICS AND MECHANISMS AT LOW PRESSURE

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Autocatalytical active bromine release from ice or snow or sea salt aerosol may be important in the marine atmosphere at high or mid-latitudes (eg EC ARCTOC and HALOTROP project reports). The importance of this process is highly dependent on the formation rate and stability of the bromine reservoirs. Reactions of Br atoms with unsaturated hydrocarbons (alkenes) have been investigated as processes which may form bromine reservoirs in the marine atmosphere. The studied reactions include : Br + ethene. propene. trans-2-butene. 2-methyl-2-butene. 2,3-dimethyl-2-butene and 1-hexene.The mass spectrometry discharge-flow method has been used at total pressure = (0.5-2.0) Torr and over the temperature range T= (233-320)K. Both hydrogen atom abstraction (forming the HBr reservoir) and addition channels have been observed for these reactions and Arrhenius expressions have been obtained for all channels.The atmospheric implications of these results will be discussed.

WHICH COMPONENTS OF THE SEA-SALT AEROSOL PROMOTE THE Br^--CATALYSED PRODUCTION OF HALOGENATED RADICALS ?

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Former smog chamber experiments (Behnke et al., 1995; 1996), field experiments (Jobson et al., 1994; Singh et al., 1996) and model calculations (Mozurkewich, 1995; Vogt et al., 1996) show that halogenated radicals are produced in the presence of seaspray aerosol and ozone. A probable reaction pathway is that BrO is produced from the reaction of ozone with Br atoms; BrO reacts with HO_2 in the gas phase to form HOBr, which is adsorbed by the aerosol surface. In the droplets of the wet aerosol HOBr reacts with Br^- or Cl^- to form Br_2 or BrCl. The reaction should be dependent on the pH value and on the the ratio Br^-/Cl^-. Iodide may have an direct influence by catalysis. Sulphate and nitrate may have an indirect influence by changing the ionic strength of the aerosol.
Our smog chamber experiments show an initial phase with very low production rate of halogenated radicals, where a few Br atoms are produced by the known reaction of OH radicals with Br^-. A second phase is governed by strong ozone degradation promoted by the production of Br_2. In our recent experiments we show that, during these two phases, the ratio Br^-/Cl^- decreases from 1/600 to less than 1/2000. A parallel decrease of the pH value down to less than three is observed. This is caused by the uptake of oxalic acid produced from the degradation of hydrocarbons. Now begins the third phase of the experiments with a smaller production rate of Br atoms but high production rates of atomic Cl. Finally the production of halogenated radicals decreases. Previously we supposed that this decrease was caused by the loss of Br^- or an increase of the pH value. But our recent measurements show that the ratio of Br^-/Cl^- increases again to 1/1000 and the pH value decreases. So the cause of the decrease of the production rate of halogenes is unclear and requires further experiments.

LABORATORY STUDIES OF THE UPTAKE OF ATMOSPHERIC TRACE GASES ON SOLID SURFACES

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Chemical interactions between gaseous trace gases and solid and liquid surfaces form an important part of atmospheric chemistry. The present project focusses on the experimental investigation of the fate of gaseous species (NO, NO_2, N_2O_5, HCl, HBr, HOCl and HOBr) on pure ice and frozen salt(acid)-solutions (NaCl, NaBr, HCl and HBr). The experiments were carried out using the coated wall flow-tube technique with the detection of gaseous species and reaction products by molecular beam QMS. Using the theory of transport and reactions in cylindrical reactors, we were able to derive the mass accommodation coefficients. The results will be discussed with regard to (i) adsorption equilibrium, surface reaction and saturation as well as (ii) the influence on the gasphase chemistry of the atmospheric trace gases in the presence of solid surfaces.

THE REACTION OF ATOMIC CHLORINE WITH BENZENE

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It is now recognized that chlorine atoms may participate significantly to the oxidation capacity of the troposphere since atom concentrations ranging from 10^4 to 10^5 molecule cm^{-3} can be predicted, as a result of chlorine activation by heterogeneous processes. On the other hand, kinetic and/or mechanistic data concerning the oxidation processes of aromatic compounds are still rather scarce. The work presented here gives a new insight into the reaction of atomic chlorine with benzene, providing information both concerning reaction kinetics and mechanisms. The experimental work, performed using flash photolysis coupled to UV absorption was complemented by quantum calculations. The rate constant of the association reaction was investigated using the relative method and was found to be very low : $k(Cl + C_6H_6) = (9.8\pm4.1) \times 10^{-15}$ cm^3 $molecule^{-1}$ s^{-1}. In fact, no reaction could be observed in the absence of oxygen, and this lead us to conclude with the establishment of an equilibrium largely shifted towards the reactants Cl and C_6H_6 . This was confirmed by the theoretical calculations which showed that the chlorocyclohexadienyl radical, the addition product, was fairly unstable. As the abstraction channel, leading to HCl and the phenyl radical, is largely endothermic at room temperature ($\approx$ 32 kJ mol^{-1}), it was considered to be inefficient. The reasons for such a slow reaction were not elucidated yet and work is still in progress.

KINETIC AND PHOTOCHEMICAL STUDIES OF IODINE OXIDE CHEMISTRY

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Halogen atoms and halogen oxide radicals X, XO where X=Cl, Br play an important role in the chemistry of the troposphere, through their participation in catalytic ozone destruction cycles. Iodine compounds have the potential to make a significant contribution to tropospheric ozone destruction, and have been proposed as a factor in mid-latitude stratospheric ozone reduction. A knowledge of the chemistry of I and IO, photochemical and kinetic data for reactions such as IO + IO, IO + XO, IO + HO_2, is necessary in order to quantify the possible role of iodine compounds in ozone destruction. The technique of laser photolysis / UV absorption spectroscopy featuring CCD detection has been used to investigate the chemistry of iodine monoxide: The absorption cross-section of the IO radical has been measured, and the kinetics of the IO + IO reaction studied as a function of temperature and pressure. OIO formation and loss in this system has been monitored, and a lower limit for the OIO absorption cross-section determined. The kinetics and products of the IO + BrO reaction have been investigated.

SPECTROSCOPIC AND KINETIC PROPERTIES OF XNO_2 (X = Br, I)

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Nitryl halides (XNO_2, X = Cl, Br, I(?)) are formed by the interaction of N_2O_5 with sea salt particles and can contribute to the radical budget in marine atmospheres. Spectroscopic and kinetic properties of these compounds are not well known. In this work, $BrNO_2$ and INO_2 were prepared in a 400 l photoreactor by photolysing $X_2/NO_2/N_2$ mixtures with light of 500 nm $\leq \lambda \leq$ 700 nm at 1000 mbar. Long-path IR (50.4 m) and UV (3.13 m) spectra could be measured simultaneously using an FTIR and a diode array spectrometer. Photostationary concentrations of XNO_2 were established after $\approx$ 660 s and 240 s, respectively, for $BrNO_2$ and INO_2. The UV-VIS spectrum of INO_2 shows local maxima at 246, 286, and 345 nm and is red-shifted as compared to the UV spectra of $ClNO_2$ and $BrNO_2$. Absorption cross sections of $BrNO_2$ as determined from a mass balance of reaction (1), $BrNO_2$ + NO => BrNO + NO, are in excellent agreement with recent data of Scheffler et al. (1997). k_1 was measured between 255 and 293 K, resulting in $k_1 = 2.3\times10^{-12}\exp(-17.9\ kJ\ mol^{-1}/RT)$ $cm^3 molecule^{-1} s^{-1}$. The observed stationary $BrNO_2$ concentrations suggest a rapid reaction between $BrNO_2$ and Br atoms. The long lifetime of $BrNO_2$ in the presence of radical scavengers supports the results of Frenzel et al. (1997) who suggested that the thermal lifetime of gaseous $BrNO_2$ is larger by four orders of magnitude than previous results of Kreutter et al. (1991).

KINETIC STUDIES OF THE REACTIONS OF THE IO RADICAL WITH ITSELF, O(^{3}P) AND HO_2.

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Iodine-containing compounds, such as CH_3I, are released into the atmosphere from several natural sources, including oceanic plankton and the burning of biomass. There are also potential anthropogenic sources of iodine, such as CF_3I, proposed as an alternative fire retardant. Iodine atoms are released principally by the photolysis of alkyl iodides, their main fate in the troposphere being reaction with ozone to produce IO radicals. The kinetic results will be presented from laboratory discharge-flow studies of the reactions of the IO radical with O(^{3}P), HO_2 and IO at room temperature, employing chemiluminescence and resonance fluorescence detection. The reaction of IO with HO_2 is thought to be important in the troposphere, and there are tentative suggestions that the reaction with O(^{3}P) may occur in the stratosphere. The self reaction of IO is of little atmospheric significance, but is of interest to those observing the reactions of IO in the laboratory. Information on the overall rate constant and the branching ratios for the different channels will be presented.

Laboratory Kinetic Studies Of The Reactions Of Cl Atoms With Species Of Biogenic Origin.

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The reactions of Cl atoms in the troposphere, particularly in polar regions and the marine boundary layer, have received increased interest in recent years. Isoprene is one of the most abundant biogenic species in the marine boundary layer, so that its reaction with Cl atoms could prove to be significant.

Values of the rate coefficients for the reactions of atomic chlorine with isoprene and its atmospheric oxidation products, methacrolein and methyl vinyl ketone, have been determined both by a relative rate technique, using gas chromatography as the detection system for the organic species, and by an absolute technique, involving the use of a discharge fast-flow system with resonance fluorescence detection of Cl atoms.

The results obtained so far of the products determined by gc-ms will be presented for the Cl atom plus methyl vinyl ketone and Cl atom plus methacrolein systems.

OBSERVATIONS OF ALKYL IODIDES AND BROMIDES AT MACE HEAD: LINKS TO MACROALGAL EMISSION AND IO FORMATION

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High frequency, in-situ GC-MS measurements of a range of biogenic short-lived alkyl halides in air including $CHBr_3$, $CHBr_2Cl$, CH_3I, C_2H_5I, CH_2ICl, CH_2I_2 and the hithero unreported CH_2IBr were made at Mace Head during a 3 week period in May 1997. Positive correlations were observed between $CHBr_3$ and $CHBr_2Cl$, CH_3I and C_2H_5I, and $CHBr_3$ and CH_2IBr throughout the campaign, providing evidence for common or linked biogenic sources. During periods when air masses were impacted by emissions from local seaweed beds, the concentrations of $CHBr_3$, CH_2ICl and CH_2IBr not only showed remarkable correlation but also maximised at low tide. These are the first field observations to provide evidence for a link between the tidal cycle and iodocarbon production. The total flux of iodine into the surface layer at Mace Head, calculated using the measured alkyl iodide concentrations, was found to be dominated by photolytic destruction of CH_2I_2. Photolysis of CH_3I contributed generally less than 5%. The peak iodine flux coincided with the highest levels of IO, measured by DOAS, during the campaign.

KINETICS OF THE UPTAKE OF D_2O AND $BrONO_2$ ON ICE

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Ice forms a significant part of tropospheric and stratospheric clouds, and is therefore an important constituent of atmospheric aerosols. Because of the role of heterogeneous reactions in the destruction of stratospheric ozone, in which surfaces are involved, it is necessary to understand how processes such as cloud formation, growth, and trace gas interactions with ice occur in the atmosphere. Therefore, the real time kinetics of D_2O condensation and evaporation of D_2O on ice have been studied in a very low pressure reactor (Knudsen Cell) using MS detection. The kinetics of adsorption has a negative temperature dependence: the condensation coefficient γ of D_2O on ice decreases from 0.30 to 0.05 over the temperature range 140 to 220K. We found also a significant dependence of γ on the method of préparation of the ice. At 180 K γ= 0.23 for a bulk ice sample, whereas for condensed ice samples γ= 0.17 . These measurements revealed a complex mechanism of interaction of D_2O on ice, involving a precursor species.
In addition, considering the possible role of heterogeneous chemistry of bromine species in the springtime depletion of Arctic tropospheric ozone, we measured the uptake kinetics of Nitrate Bromine $BrONO_2$ on ice at temperatures of atmospheric interest both with and whithout HCl and HBr. Possible atmospheric implications of this work will be discussed.

REACTIVE BROMINE IN THE MARINE BOUNDARY LAYER: LABORATORY STUDIES OF GAS-PHASE AND HETEROGENEOUS PROCESSES.

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Reactive bromine species (Br, BrO and HOBr, Br_2 and BrCl) play a central role in episodic depletion of ozone in the polar lower troposphere and may be important for the remote MBL. HOBr links the gas- and aqueous phases where it takes part in ozone destroying catalytic cycles and in liquid phase reactions that convert Br^- to the insoluble, photolabile molecular halogens Br_2 and BrCl, respectively. In the present study, we have examined the efficiency of halogen activation via the heterogeneous reaction of HOBr on sea-salt aerosol (1a and 1b), made new measurements of the absorption cross-sections and J-values of HOBr (2), and made kinetic measurements of the reaction between BrO and DMS (3).

$HOBr + Br^-$	$\rightarrow$	$Br_2 + OH^-$	(1a)
$HOBr + Cl^-$	$\rightarrow$	$BrCl + OH^-$	(1b)
$HOBr + h\nu$	$\rightarrow$	OH + Br	(2)
BrO + DMS	$\rightarrow$	products	(3)

The relevance of these results to our present understanding of halogen chemistry in the MBL is discussed.

Kinetics of the heterogeneous reaction of HNO_3 with NaCl: Effect of Water Vapour

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Abstract

We report [illegible] of the uptake of HNO_3 on salt films and crystallite grains in a wall coated tubular flow reactor coupled to a quadrupole mass spectrometer. Uptake coefficients were measured at room temperature with a range of partial pressures of HNO_3 and H_2O in the flow tube. γ vaues decreased with increasing HNO_3 concentration (1 to [illegible]00 x 10^{11} molecule cm^{-3}), and increased with H_2O over the range 0.00[illegible] to [illegible] mbar. The results were interpreted in terms of a mechanism of the reaction: HNO_3 + NaCl(s) $\rightarrow$ HCl + $NaNO_3$ which involves protonation of surface adsorbed [illegible] adsorbed HNO_3 molecules, followed by reaction with Cl^- and desorption [illegible] molecules. The results allow estimation of the reactive uptake coefficient [illegible] HNO_3 on sea salt aerosol under a variety of atmospheric conditions.

Modelling of low ozone measured at the West Coast of Ireland

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A boundary-layer measurement campaign was held on the West Coast of Ireland during the summer of 1996 as part of the UK programme 'Atmospheric Chemistry Studies in the Oceanic Atmosphere' (ACSOE). Periods of low ozone concentrations (e.g. 8-14 ppbv) were observed during the campaign. The Cambridge Tropospheric Trajectory model of Chemistry And Transport (CiTTy CAT) has been used to investigate both meteorological and chemical explanations for these observations. Back trajectories show the meteorological importance of the Azores high during these low ozone periods. This may offer a simple transport and chemical explanation for the low ozone; tropical air may be advected northwards with in-situ ozone destruction by photolysis and reaction of $O(^1D)$ with water vapour. Measurement of high concentrations of methyl iodide at the site concurrent with these low ozone episodes suggests the possibility that a loss mechanism involving halogens may in part explain these observations. These two possible explanations are evaluated.

FIRST DOAS MEASUREMENTS OF TROPOSPHERIC BRO AT MID LATITUDES: THE DEAD SEA VALLEY AS A NATURAL LABORATORY

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In the mid 80^{th} sudden boundary layer ozone depletion events were discovered in arctic spring. The simultaneously high BrO concentration awoke the interest in the sources and chemistry of halogen oxides in the troposphere. Recently the influence of BrO, ClO and IO on the mid latitude boundary layer chemistry was examined. Since sea salt is suspected to be a source of halogens, most of the investigations have been concentrated on coastal clean air sites like Mace Head (Ireland). So far no BrO has been found at low and mid latitudes.
In spring 1997 a campaign of the Hebrew University Jerusalem and the University of Heidelberg was performed at the Dead Sea. By using DOAS (Differential Optical Absorption Spectroscopy) and some other different analytical systems BrO and a number of other species, i.e. SO_2, NO/NO_y, CO, O_3 were measured. During a period of 4 weeks we observed repeating patterns of BrO and O_3. The daily variation of the concentrations showed high values of BrO correlated ozone depletion during late morning. The special morphological situation indicates the Dead Sea Valley to be a perfect outdoor laboratory to observe the influence of BrO on boundary layer ozone depletion.

SPECTROSCOPIC AND KINETICAL INVESTIGATION ON BRO APPLYING STATIC AND TIME RESOLVED RAPID SCAN FT-UV SPECTROSCOPY

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We present results of photolysis experiments with gas mixtures of Br2 and O3 in a cooled flow cell. A flash photolysis setup was used to initiate homogeneous reactions at stratospheric temperatures. Reaction products as well as intermediate species were observed by UV absorption measurements. A recently developed Rapid Scan method was used to achieve time resolved spectra. Synchronizing the flash photolysis experiment to the FT scan mirror we observed the dynamical processes in the reactions between Br and O3, yielding information about reaction kinetics. In addition, the FT-UV spectrometer was employed in static mode in order to record high resolution spectra of BrO at temperatures down to 213 K.

MECHANISTIC CONSIDERATIONS FOR TROPOSPHERIC HALOGEN ACTIVATION IN THE MARINE AEROSOL

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Results from laboratory and modelling studies of the formation and reactivity of aqueous phase free radicals which may be involved in the process of tropospheric halogen activation within the marine aerosol will be presented. Laser-based methods have been developed and applied for the generation and time-resolved detection of radical species. Modelling has been applied to discuss complications in the HOBr-based halogen activation process under low NO_x-conditions. By reaction of HOBr with HO_2/O_2^- in the aqueous aerosol, the non-radical halogen activation process may be accompanied by aqueous phase radical processes involving the bromine atom and the radical-anions $BrCl^-$, Br_2^- and Cl_2^-.
Contributions of reactions of the above-mentioned free radicals to the overall chemical conversions in the tropospheric marine aerosol will be discussed by means of the recently developed chemical aqueous phase radical mechanism (CAPRAM). This box model combines the well known gas phase RADM2 chemical mechanism with an extended set of aqueous phase chemical reactions taking into account numerous chemical reactions in the aqueous phase. An outlook on potential developments and open questions with regards to both modelling as well as future laboratory studies for understanding the marine aerosol halogen activation process will be given focussed on conversion processes in the aqueous phase.

MECHANISM OF NO_3 UPTAKE BY SOLID NaCl

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Chemical mechanism of NO_3 uptake on solid NaCl surfaces has been studied by means of matrix isolation/ESR (MIESR) and mass-spectrometry (MS) with variable level of electron impact ionization. The method of mobile rod covered by NaCl was used to infer main features of NO_3 uptake chemistry on solid and humidified NaCl. Three types of covering have been tested: 1. spirit solution spray. 2. water solution spray. 3. rod immerging in concentrated water solution and slow drying in air.
Low $[NO_3]=(3*10^9-5*10^{11}\ cm^{-3})$ were studied with the MIESR technique while high $[NO_3]=(3-5)*10^{13}\ cm^{-3}$ were detected in MS studies. In MS experiments Cl atom was the primary product of heterogeneous reactions: (1a) $NO_3+NaCl=Cl+NO_2$ or (1b) $NO_3+NaCl=1/2Cl_2+NaNO_3$. ClO and NO_2 formed in reaction (2) Cl+NO3=ClO+NO_2 were observed and the balance of NO_3 consumed vs. NO_2 formed was established. At low $[NO_3]$ reaction (2) is most probably suppressed by heterogeneous recombination of Cl atoms with liberation of Cl_2. In presence of H_2O vapor $(\sim 10^{14} cm^{-3})$ HCl formation was observed. An attempt to explain the morning hydrocarbons' consumption. observed in Pacific Exploratory Mission has been done.

REACTION RATE AND CHEMICAL MECHANISM FOR THE GAS PHASE REACTIONS OF Cl ATOMS WITH CH_2ICl AND CH_2I_2

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Iodinated compounds have been detected in the lower troposphere and in marine environments in the range of several ppt. They are mainly emitted by biogenic processes that occur in the marine boundary layer. Their tropospheric degradation mechanism is important in the understanding of the atmospheric chemistry of Iodine atoms. In general, iodinated compounds are very photolabile species and probably undergo efficient photodissociation in the troposphere. However, they may also react mainly with OH radicals, or probably with halogen atoms in marine environments where the concentration of halogenated species is high. This work studied the homogeneous reaction of Cl atoms with two iodomethanes of biogenic origin, CH_2ICl and CH_2I_2 at very low pressures, by using the Very Low Pressure Reactor (VLPR) technique. The absolute rate constants at room temperature were greater than $1 \times 10^{-11}\ cm^3\ molecule^{-1}\ s^{-1}$, suggesting that both reactions occur via the formation of an intermediate weak adduct between the incoming Cl atom and the iodine end of the molecule. Mass spectrometric analysis of the reaction products revealed the appearance of ICl and HCl as final products, with no evidence of the I atom displacement reaction.

LOW TEMPERATURE FTIR-STUDIES AND AB-INITIO CALCULATIONS OF BrOBr and BrBrO

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The reversible photoinitiated isomerization reaction of BrOBr to BrBrO was measured in solid argon matrices and calculated by multiconfigurational quasidegenerate perturbation theory (MCQDPT). The calculated vertical excitation energies are in good agreement with the experimentally observed excitation wavelengths.

While the isomerization from BrOBr to BrBrO appears to be quantitative, some product loss is observed during the back reaction. The calculated excitation energies and oscillator strengths for transitions from the ground to excited states offer a detailed explanation of this behaviour.

All three fundamentals of BrOBr and BrBrO could be observed. The previously unknown frequencies of the bending vibrations were located at 177.0 cm^{-1} for BrOBr and at 170.6 cm^{-1} for BrBrO. In addition the UV-spectrum of BrBrO has also been measured.

UV-VISIBLE ABSORPTION CROSS-SECTIONS AND ATMOSPHERIC LIFETIMES OF CH_2Br_2, CH_2I_2 AND CH_2BrI

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The UV-visible absorption spectra of CH_2Br_2, CH_2I_2 and CH_2BrI, which have been found in the troposphere, have been measured over the wavelength range 215-390 nm using a dual beam diode array spectrometer. The spectra consist of broad continuous absorption bands. CH_2Br_2 exhibits its maximum cross-section of $\sigma = 2.71(\pm0.16)\times10^{-18}$ $cm^2molecule^{-1}$ at $\lambda = 219$ nm. The magnitude of the peak cross-sections for the iodine containing molecules are $\sigma = 1.62(\pm0.10)\times10^{-18}$ $cm^2molecule^{-1}$ at $\lambda = 248$ nm and $\sigma = 3.78(\pm0.23)\times10^{-18}$ $cm^2molecule^{-1}$ at $\lambda = 288$ nm for CH_2I_2, and $\sigma = 5.67(\pm0.34)\times10^{-18}$ $cm^2molecule^{-1}$ at $\lambda = 215$ nm and $\sigma = 2.34(\pm0.14)\times10^{-18}$ $cm^2molecule^{-1}$ at $\lambda = 267$ nm for CH_2BrI. The temperature dependence of the absorption cross-sections was investigated over the temperature range 348 K to 250 K. A decline in the cross-sections with decreasing temperature was observed in the tail of the spectra. At the peaks the opposite effect was observed. The photolysis rates of CH_2Br_2, CH_2I_2 and CH_2BrI were calculated as a function of altitude and solar zenith angle using the measured cross-sections. Model calculations show that during sunlit hours CH_2I_2 and CH_2BrI will be photolysed within minutes and hours respectively. The reaction with the OH radical was found to be the dominant loss process for CH_2Br_2.

THEORETICAL AB-INITIO CALCULATIONS OF THE STRUCTURE AND STABILITY OF HALOGEN ATOMS ADDUCTS WITH ALKYL HALIDES

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There is growing experimental evidence that the reactions of alkyl halides with electrophilic groups, such as F and Cl atoms, occur via the formation of an intermediate adduct between the incoming group and the electron-rich site of the halide molecule. The present work has performed systematic theoretical calculations in order to elucidate the relation between structure and stability in a series of the adducts between F and Cl atoms (X') and several substituted bromo- and iodo-methanes (RX). The ab-initio calculations were performed at the MP2/3-21++G(2d,2p) level of theory for all species, and were repeated at the MP2/6-31++G(2d,2p) level for the adducts of bromomethanes. The structure of these adducts was generally characterized by very close R-X-X' angles (ca. 80 degrees) and minor perturbation of the structural parameters of parent halide molecule. The depth of potential well of the RX-X' interaction was found to depend upon the relative electronegativities of the two halogen atoms X and X', and was deeper for the RI-F adducts (ca. 100 kJ mol^{-1}), while the degree of halogen atom substitution on the carbon atom was found to decrease the potential well. Vibrational frequencies of all species were calculated and the corresponding reaction enthalpies and the X-X' bond strengths of the adducts at 0 K and 298.15 K were also derived.

THE Cl ATOM OXIDATION OF ISOPRENE STUDIED IN THE LABORATORY

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The reaction of Cl atom initiated oxidation of isoprene ($CH_2=C(CH_3)-CH=CH_2$ or C_5H_8) is of potential importance in the marine atmosphere, where both Cl atoms and isoprene can be simultaneously present. The chlorinated oxidation products from this natural source may influence the tropospheric budget of chlorinated species. In relation to this issue, the kinetics and mechanism of the Cl + isoprene reaction has been investigated. The rate constant of this reaction has been determined as function of temperature and pressure using two complementary methods: discharge flow-mass spectrometric and laser photolysis-resonance fluorescence. The main value obtained at 298 K is k(Cl + isoprene) = $(3.5 \pm 0.1) \times 10^{-10}$ cm^3 $molecule^{-1}$ s^{-1}. Besides, the discharge flow study showed evidence for two channels: addition of Cl atom and HCl elimination. The HCl yield was measured as function of temperature and found to be 0.17 ± 0.02 at 298 K. The atmospheric implication of these data will be discussed.

TROPOSPHERIC OZONE DEPLETION AND RELATED HALOGEN CHEMISTRY AT POLAR REGIONS

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Since one decade the phenomenon of tropospheric ozone depletion during spring has been reported from several Arctic stations and recently also from Neumayer, the German overwintering station in Antarcica. Simultaneously to tropospheric ozone loss enhanced levels of BrO (measured by DOAS) and f-Br (non sea salt bromine collected on cellulose filters) could be observed. While the mechanism of ozone depletion seems to be caused by a chemical reaction cycle including free halogen radicals and halogen oxides, the source of these reactive halogen species is still unclear.
In our presentation we will summarise our continous ozone, DOAS and aerosol filter measurements of two field campaigns in the framework of the EU project ARCTOC during spring '95 and '96 at Spitsbergen/Arctic. We will give an interpretation of the coupling between observed ozone and halogen species (i.e. BrO and f-Br), which is consistent with the proposed autocatalytical recycling of reactive halogen species.
With the help of ozone and halogen data from the Neumayer station a comparison of tropospheric ozone loss at the polar regions of both hemispheres will be presented. Special focus will be put on the differences in seasonality, temporal extension and frequency of the phenomenon.

FORMATION OF HALOGENS FROM THE HETEROGENEOUS REACTION OF SEA SALT

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The heterogeneous reactions of the sea salt particles with gases have been recognized as important sources for halogens in the troposphere in the marine boundary region as well as in the Arctic. A newly constructed aerosol chamber is equipped with long-path (150 m) Fourier-transform infrared (FTIR), differential optical absorption spectroscopy (DOAS), and atmospheric pressure ionization mass spectrometry (API-MS). Recently, studies on reactions of sea salt with O_3 have shown the formation of Cl_2 from the photolysis of O_3 in the presence of sea salt particles above their deliquescence point at room temperature, implying a potential source for Cl atoms in the tropospheric marine boundary layer. However, the formation of Br_2 dominated in the reaction of sea water ice with O_3 in the dark. This may be the potential source for Br atoms initiating the ozone depletion in Arctic during polar sunrise. Reaction mechanisms for generation of Cl_2 and Br_2 will be discussed. Studies on sea salt particles with oxides of nitrogen such as NO_2, N_2O_5, HNO_3 and $ClONO_2$ will be also presented.

A NOVEL APPROACH TO DERIVE INTEGRATED HALOGEN ATOM CONCENTRATIONS FROM CHANGES IN VOC PATTERN DURING TROPOSPHERIC OZONE DEPLETIONS

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Tropospheric ozone depletions have been observed in the arctic for more than 15 years. These are caused by significant concentrations of bromine and chlorine atoms. Yet, no direct measurement technique for quantifying the amounts of free halogen atoms in ozone depleted air masses is available. However, the chlorine and bromine concentrations can be estimated from changes in hydrocarbon pattern. This method depends crucially on the estimate of initial hydrocarbon mixing ratios, which have been in the air mass before chlorine and bromine where injected. During spring the arctic troposphere is assumed to be well mixed. Thus, the initial mixing ratios should be similar to the mixing ratios in air masses with typical ozone levels (30-40 ppb). Since ozone depleted air masses are always isolated from the background atmosphere by inversions, it should be examined how reliable those estimates of initial mixing ratios are. Changes in the pattern of selected organic trace gases determined during the ARCTOC 96 experiment at Ny Ålesund, Spitsbergen, have been investigated for chemical processing and mixing. The results confirm the assumption of an initially well-mixed spring arctic troposphere. The integrated halogen atom concentrations derived in this study agree well with earlier estimates.

GOME MEASUREMENTS OF TROPOSPHERIC BRO IN NORTHERN HEMISPHERIC SPRING

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Periods with enhanced tropospheric BrO concentrations have been reported by several groups both for the Arctic and Antarctic spring. These episodes are often correlated with decreasing tropospheric ozone concentrations and therefore an indication of bromine catalysed tropospheric ozone destruction.
In this study, measurements of the satellite instrument GOME have been evaluated for absorptions by tropospheric BrO. These data give for the first time a global view of the phenomenon. Both the geographical extension and the temporal evolution of the tropospheric BrO events will be discussed for the first half of 1997. The global coverage of the GOME instrument also allows a rough estimate of the contribution to the tropospheric bromine loading in the northern hemisphere.

THE UV ABSORPTION CROSS-SECTION AND ATMOSPHERIC PHOTOLYSIS RATE OF HOI

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Gas phase hypohalous acids, HOX (X = Cl, Br, I) act as temporary halogen reservoir species throughout the atmosphere. HOX species are formed in the gas phase reaction of the halogen monoxide (XO) species with HO_2. Subsequent photolysis of HOX to yield OH + X can lead to completion of a catalytic cycle for ozone destruction. A recent modelling study has shown that HOI is the main iodine containing species in the troposphere.
In this work, we have measured the UV-visible absorption cross-sections of HOI, in order to determine its lifetime with respect to solar photolysis in the atmosphere. HOI was prepared in a flash photolysis apparatus using the gas phase reaction of OH radicals with I_2. The UV spectrum of HOI was recorded using a CCD detector and calibrated by measuring consumption of I_2. The absorption cross-section of HOI was used to calculate the solar photolysis rate of HOI in the troposphere.

MODELING THE CHEMISTRY OF OZONE AND HALOGEN COMPOUNDS IN THE MARINE BOUNDARY LAYER

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The box model 'MOCCA' (Model Of Chemistry Considering Aerosols) has been developed to study the tropospheric chemistry in the marine boundary layer (mbl). The chemical mechanism considers gas-phase reactions as well as aqueous-phase reactions in sulfate and sea-salt aerosol particles. Photochemical reactions are switched on during daytime. Their rates vary according to the solar declination. Apart from the standard tropospheric HO_x, CH_4, and NO_x chemistry, the chemical reaction mechanism includes sulfur, chlorine, bromine, and iodine compounds. Model results were published for the polluted mbl (*J. Geophys. Res.* **101D**, 9121-9138, 1996) as well as for the remote mbl (*Nature* **382**, 327-330, 1996).
Current model development focusses on four aspects: 1) The effect of aerosol acidity on aqueous-phase chemistry; 2) Analysis of the marine iodine chemistry; 3) Explicit calculation of aerosol chemistry as a function of aerosol size; and 4) The effect of cloud processing on aerosol chemistry. Latest results will be presented.

MULTIPHASE PHASE CHEMISTRY OF XNO2 AND HOBR IN RELATION TO TROPOSHERIC HALOGEN ACTIVATION

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Halogen activation has been observed in the marine boundary layer (MBL) both inpolluted and remote locations. The reactions, that are thought to be essential for maintaining large amount of photochemically active species in the gas phase, are :

$$HOBr + Y^- \rightarrow \text{products}$$
$$XNO_2 + Y^- \rightarrow \text{products}$$

where Y^- represents Cl^-, Br^- or I^-. In order to get a throughout understanding of the rapid loss of surface ozone in the MBL, it is therefore necessary to investigated the kinetics of these reactions and to identify the potential products.
We performed such a study using the droplet train and wetted-wall techniques coupled to infrared and mass detection facilities. Current results describing the effect of temperature, aqueous phase composition on the uptake rates will be presented.

HETEROGENEOUS REACTIONS OF HALOGEN CONTAINING TRACE GASES ON NACl AND KBr SALT

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Heterogeneous reactions of bromine containing atmospheric trace gases on sea-salt aerosols are assumed to be responsible for the sunrise chemistry leading to significant tropospheric ozone depletion in the Arctic. We studied the heterogeneous reactions of XNO_2, $XONO_2$ and HOX (X = Cl, Br) on NaCl and KBr salt using a Knudsen reactor equipped with mass spectrometry and laser induced fluorescence detection.
Uptake coefficients involving Br-containing compounds are found to be higher than the corresponding Cl-containing reactions. As products we observed Br_2, BrCl and Cl_2 depending on the gas and solid phase. We will present the kinetics and mechanism of these reactions. By using salt samples of well-defined total external surface and applying a pore diffusion model to the obtained uptake rates we consider diffusion of the gas into the bulk of the salt sample and thus determine true uptake coefficients γ_0. Furthermore we will discuss the role of water absorbed on the salt surfaces. In order to expand our data to more realistic surfaces we also present some results using synthetic sea-salt samples.

STUDY OF IODINE OXIDES AND IODINE OZONE CHEMISTRY USING FLASH PHOTOLYSIS AND TIME RESOLVED ABSORPTION SPECTROSCOPY

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Based upon observations of IO and OIO absorption spectra reported earlier (Himmelmann et al. 1996) the gas phase reactions of the I+O3 system following the photol yzation of I2 in the presence of O3, O2 and N2 were investigated. The experiment comprised of a flash photolysis set-up and two time resolved absorption spectroscopy systems using a photomultiplier tube PMT and a photodiode array PDA. The measurements were performed at room temperature 293,7 K and at pressures ranging from approximately 10 to 50 mbar. In addition to the absorption spectra of O3, I2, IO and OIO four new absorbers could be observed, one of those having been reported earlier by Sander (Sander 1986). For two of theses absorbers it was possible to record qualitative absorption spectra yet without absolute scaling of the absorption cross section axis=2E Using the monitored temporal behaviour of the main components O3, I2, IO and OIO, estimates for the cross sections sIO and sOIO and for the rate constants of the first reactions following the production of IO were determined. This work was partially funded by the German Space Agency DARA (contract 50EP9207), the Commission of the European Community (contract EV5V-CT93-0338), and the University and the State of Bremen.

EMISSION OF REACTIVE ORGANOCHLORINES AND ORGANOBROMINES FROM COASTAL MACROPHYTES

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A number of macrophytes from the Norfolk coast were incubated in the laboratory and emissions of volatile organohalogens determined. A large number of chlorinated, brominated and iodinated organics were detected. Attention here is focused on the chlorinated compounds and their potential contribution to atmospheric levels. A GIS analysis was used to determine gridded global coastal zone areas. Combining emission rates (including previously published data), with coastal area, average biomass loadings, and latitudinally-weighting primary productivity, yields annual emission rates by latitude. Globally integrated emissions amounted to 4 tonnes Cl per year from $CHCl_3$, 0.5 tonnes Cl per year CH_3Cl, and just 0.01 tonnes per year CH_2Cl_2. For $CHCl_3$ and CH_3Cl these concentrations are comparable with industrial emissions, but fall far short of total global emissions. Local levels in coastal regions may, however, be significant. The impact of organobromine emissions are also assessed.

CHEMISTRY OF HALOGEN OXIDES IN THE TROPOSPHERE: COMPARISON OF MODEL CALCULATIONS WITH RECENT FIELD DATA

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The discovery of sudden boundary layer ozone depletion events in the arctic spring and the simultaneously elevated bromine concentrations raised the interest in the sources and the chemistry of halogens in the troposphere. While the identification of BrO by differential optical absorption spectroscopy (DOAS) confirmed the catalytic processes responsible for the destruction of ozone by BrO and possibly also ClO and IO, the circumstances leading to the formation of the halogen oxides in these environments remain unclear. Recent DOAS measurements have found elevated BrO and IO levels at the Dead Sea. Israel and at Mace Head, Ireland respectively, showing that tropospheric halogen liberation also occurs at mid latitudes.

Model calculations describing the tropospheric halogen chemistry in the arctic and at mid latitudes are presented. The calculations aim to improve the understanding of the multiphase chemical processes leading to the formation of BrO and IO in the different environments. The influence of the measured halogen oxide concentrations on ozone is also discussed.

THE CHEMISTRY OF IODINE IN THE MARINE BOUNDARY LAYER

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Measurement of organic iodine compounds indicate that species, such as CH_2I_2 and C_3H_7I. might have a much larger source strength than CH_3I, the only organic iodine compound which is commonly accounted for in the global iodine budget. Organic iodine compounds are formed in biogenic processes of certain macroalgae and phytoplankton. Because of the supersaturation of the surface water these compounds evaporate and can be detected in the marine air.

We have incorporated such compounds. together with the latest photolysis rate data. into our photochemical box model. Partitioning of iodine between the gaseous and particulate phase is calculated and the impact on the ozone budget in the remote marine boundary layer is investigated.

GOME OBSERVATION OF ENHANCED TROPOSPHERIC BRO CONCENTRATION IN THE POLAR SPRING

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Since about a decade now the phenomenon of complete ozone depletion in the Arctic boundary layer is known, it was recently also found in Antarctica. While during the last years it was shown that these O_3 loss events are caused by BrO-catalysed O_3 destruction the origin of the high BrO concentrations remained unclear. Here we present the first satellite measurements of enhanced tropospheric BrO columns in the Arctic and Antarctic spring. The observed tropospheric BrO vertical column densities are up to $5 \cdot 10^{13}$ molec/cm^2 on top of a stratospheric column of about $2.5 \cdot 10^{13}$ molec/cm^2. Thus the derived tropospheric mixing ratios of about 35 ppt (if a layer thickness of 1 km is assumed) are in good agreement with ground based observations. From satellite observations it is possible to study directly the spatial and temporal evolution of airmasses with enhanced tropospheric BrO concentrations. We present several case studies of enhanced tropospheric BrO. For all of these observations the BrO concentrations stay elevated for about 1 - 3 days thus supporting the theory involving autocatalytic Br release, probably from sea salt deposits on the sea ice.

DOAS UV/VISIBLE MEASUREMENTS AT NY-ÅLESUND 1995-1997: RETRIEVAL OF TROPOSPHERIC CONSTITUENTS

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Measurements and modeling studies strongly suggest that depletion of ozone in the Arctic boundary layer is due to catalytic destruction by halogenous cycles. In this study three years of observations of BrO, OClO, and IO by means of zenith sky differential optical absorption spectroscopy are presented. These measurements are complemented by comparison with observations by the satellite instrument GOME onboard ERS-2.

High tropospheric amounts of BrO could be observed from the middle of March to the beginning of June every year. They are always correlated with low amounts of boundary-layer ozone. From the data BrO concentrations of up to 40 ppt in the lower troposphere are derived. Further, in a few cases significant levels of OClO and possibly IO could be observed. Upper limits of 15 ppt (OClO) and 10 ppt (IO) in the boundary-layer could be estimated. This is the first hint, that IO is present in the atmosphere in considerable amounts.

OBSERVATIONS AND MODELLING STUDIES OF REACTIVE IODINE SPECIES IN THE MARINE BOUNDARY LAYER

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Following field studies of the Iodine Oxide Radical (IO) during three measurement campaigns in the Northern Hemisphere, extensive modelling studies were made to investigate the sources, sinks and potential impact of reactive iodine in the marine boundary layer. It has been hypothesised that IO may be involved in autocatalytic cycles which have a significant effect on the depletion of tropospheric ozone and are responsible for modulation of the NO_2/NO and HO_2/OH ratios. Following measurements of the organic iodine precursors and of aerosol size distributions, it has been possible to model the sources and sinks of inorganic iodine and hence to infer the heterogeneous chemical behaviour of inorganic iodine species required to produce the observed levels of IO. The importance of reactive iodine species in the destruction of tropospheric ozone has also been assessed. DOAS measurements of IO during the three measurement campaigns will be presented along with the modelling results.

BROMINE RADICALS AND PHOTOLYSABLE HALOGEN COMPOUNDS DURING POLAR SUNRISE AT ALERT, CANADA

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Two instruments were used to measure halogen species at Alert NWT Canada, during the spring of 1997. A modified radical amplifier measured the bromine radical (Br, BrO) concentrations and an updated photolysable halogen detector (PHD) measured the compounds capable of producing halogen radicals. This detector can now distinguish between species on the basis of their photolytic lifetime. in this case it was configured for HOX and X_2. Two ozone depletion events were studied. Higher bromine radical and photolysable halogen concentrations were observed as the atmosphere returned from an ozone depletion event to normal conditions. The dominant photolysable species was identified as HOX, particularly for X=Br.

OA19 Free-radicals in the troposphere (co-sponsored by ST)

Convener: Dorn, H.-P.
Co-Convener: Volz-Thomas, A.

STUDIES OF THE NITRATE RADICAL IN THE TROPOSPHERE

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The technique of differential optical absorption spectroscopy (DOAS) has been used to study the nitrate radical (NO_3) in several major field campaigns in the marine boundary layer (MBL). Concentrations as high as 10 ppt have been observed in clean marine air. An extensive set of ancillary measurements acquired during these campaigns allows nearly complete closure to be obtained on the loss processes of NO_3 in the MBL. A second zenith pointing DOAS instrument has also been deployed at the same sites in order to retrieve the column abundance of NO_3 throughout the troposphere during sunrise. By combining data from both instruments the column abundance of NO_3 in the free troposphere has been estimated and found to be very variable, ranging from 2×10^{13} to 5×10^{14} molecule cm^{-2}. Under favourable circumstances, the vertical profile of NO_3 up to the lower stratosphere can also be retrieved by this technique.

SIMULTANOUS DOAS-MEASUREMENTS OF HONO AND ITS PRECURSORS IN A TRAFFIC TUNNEL

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Nitrous acid (HONO) plays an important role in photochemical air pollution through its photodissociation by solar UV radiation into hydroxyl radicals (OH + NO), thus promoting atmospherical photochemistry. Therefore the production of O_3 and other secondary pollutants should be enhanced by the formation of HONO. In the early morning photolysis of HONO leads to OH production rates up to some 10^7 OH radicals cm^{-3} s^{-1}. Simultanous measurements of HONO and NO_2 using a multi reflection DOAS system and NO by in-situ analyzer were performed in a heavily used traffic tunnel. Additionally the ambient concentrations of HONO, NO_2 and NO were measured outside the tunnel. The HONO concentration in relation to the traffic density can be used to estimate the amount of primary HONO emission. Furthermore the heterogenous formation of HONO from NO_x on the walls of the tunnel can be investigated at times of low traffic densities. The emission of HONO from the tunnel into the urban atmosphere is estimated and discussed in the light of its potential as a photochemical OH source.

ROLE OF PEROXY RADICALS IN THE FORMATION OF TROPOSPHERIC OZONE IN BREMEN

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The role of peroxy radicals ($HO_2 + \Sigma\ (RO_2)$) in the photochemical cycles of the troposphere is recognized to be of major significance for the composition of the troposphere, the latter impacting on local pollution events and potentialy on the climate. HO_2 and RO_2 have singled out as being of special importance in the formation of tropospheric O_3 . The chemical amplification (CA) is the technique which has been used to measure total peroxy radicals (RO_x = OH+ HO_2 + RO+ RO_2).The CA is based on the conversion of peroxy radicals into NO_2 by addition of NO and CO, and NO_2 ulterior measurement via its chemiluminiscent reaction with luminol. The detection limit is estimated to be 3-5 ppt RO_x depending of atmospheric conditions. During episodes of elevated boundary layer O_3 concentrations, observed in Bremen between 1995 and 1997, measurements of RO_x, coupled with NO, NO_2, CO, O_3, UV-A, UV-B, meteorological parameters and recently PAN (peroxyacetyl nitrate) were performed. These data have been analysed using empirical approaches and a simple atmospheric model. The results and their significance for our understanding of tropospheric chemistry in the boundary layer will be discussed .

TESTS AND EVALUATION OF AN ION ASSISTED MASS SPECTROMETRIC TECHNIQUE FOR LONG-TERM MONITORING OF ATMOSPHERIC OH-RADICALS

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Atmospheric OH-radicals are measured with an improved ion assisted mass spectrometric technique based on OH titration with SO_2 and conversion to HSO_4^- ions at atmospheric pressure. The present system was developed for both mobile and stationary measurements of OH as well as gaseous sulfuric and methane sulfonic acids with detection limits in the low 10^5 cm^{-3} range. In future applications the system will be mainly used for long-term monitoring of OH and sulfuric acid at the Hohenpeissenberg observatory in conjunction with a large set of atmospheric trace gas, aerosol, and meteorological measurements. Details of the system are presented, results obtained from calibration checks based on photolysis of ambient H_2O are discussed, and various tests for possible interferents (e.g., reactant impurities), ambient air pollution (NO_x), and wind turbulence effects are evaluated for possible error contributions. First measurements in ambient air indicate a good correlation between daytime OH signals and global radiation flux. Further tests, parallel ozone photolysis measurements, and a field intercomparison with the Juelich DOAS and LIF techniques are planned for the near future.

MODELLING RADICAL CHEMISTRY IN THE MARINE BOUNDARY LAYER

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The hydroxyl (OH) radical has long been recognised as the most important oxidising species in the earth's troposphere, and is largely responsible for the removal of many man-made and natural trace gases. In recent years, there have been several field studies where the concentration of OH has been determined in the atmosphere, and modelling studies have complemented these measurements. In general, the models have tended to over estimate the OH concentration. In this paper we discuss two campaigns that have been recently held at Mace Head on the west coast of Ireland, as part of the ACSOE EASE96 and EASE97 campaigns. The Mace Head site is typically subject to very clean air when the flow is from the west. However, dirty air masses are also experienced that have often passed over mainland Europe or the UK before reaching Mace Head. These varying conditions give us an excellent chance to thoroughly test models of atmospheric chemistry. During these campaigns, the concentration of OH and HO_2 were determined by Fluorescence Assay by Gas Expansion (FAGE) and the concentration of the sum of peroxy radicals by chemical amplification. A box model has been constructed to predict the concentrations of these radicals, and these predictions are compared to those measured in the atmosphere. We also present a detailed analysis of the most important reactions in the remote marine boundary layer.

INFERRING OH CONCENTRATIONS FROM DIURNAL VARIATIONS OF NON-METHANE HYDROCARBONS

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Daily mean hydroxyl radical (OH) concentrations at a rural site in Switzerland are inferred from diurnal variations of ratios of non-methane hydrocarbons (NMHCs). Suitable combinations of NMHCs are selected by examining the sensitivity of the derived OH concentrations on the difference between the respective NMHC reactivities toward OH. Calculated OH-concentrations average in summer to 3 x 10^6 molec cm^{-3}. This figure is consistent with model results and direct measurements in moderately polluted air in Europe.
Derived concentrations show a significant correlation with the daily maximum global radiation and the daily maximum ozone concentration. Both quantities are known to play an important role in the formation of the OH-radical. Calculated regression curves of OH against these parameters for the summer of 1996 are tested against those computed for the summer of 1997. Changes in the regression coefficients are discussed with respect to variations in meteorological conditions and precursor levels.

PEROXY RADICAL INITIATIVE FOR MEASUREMENTS IN THE ENVIRONMENT (PRIME): A NEW EU PROJECT

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PRIME aims to develop improved instrumentation for measurements of HO_2 and RO_2 radicals in the troposphere using the Chemical Amplification (CA) and Fluorescence Assay by Gas Expansion (FAGE) techniques. The improvements will address the specificity, sensitivity, accuracy and precision of the measurements. Novel CA and FAGE inlet systems will be constructed. Better characterised and new calibration sources for OH, HO_2, CH_3O_2 and $CH_3C(O)O_2$ radicals will be developed. Numerical models incorporating gas-phase and heterogeneous chemical reactions and physical fluid dynamical processes will be applied to aid the design and characterisation of the inlet systems and calibration sources. The improved instrumentation will be evaluated in a field measurement study in the summer of 1999 at the Silwood Park Atmospheric Research Station, near London. The field study is designed to compare ambient measurements of peroxy radicals using CA and FAGE under challenging sub-urban conditions. A deeper understanding of the sources and sinks of peroxy radicals will also be gained through the application and validation of the MCM/PTM model of tropospheric photochemistry and transport.

CHEMICAL PROCESSES AFFECTING THE GLOBAL DISTRIBUTION OF OH IN A TROPOSPHERIC LAGRANGIAN CHEMISTRY MODEL.

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A three-dimensional Lagrangian tropospheric chemistry model was used to simulate the global distribution of the OH radical. This model also provided a budget of all the OH production and destruction terms. To verify the free radical distribution the model simulated the lifetime of methylchloroform and the distribution of 14-CO which were then compared against measurements. As a sensitivity test the reaction coefficients for each of the major processes affecting OH were varied in turn by their published tolerances. This test showed that the uncertainties in the basic chemical kinetic data leads to significant uncertainties in the global OH distribution
Our chemistry scheme contains 70 species including the non-methane hydrocarbons: ethane, ethene, propane, propene, butane, toluene, o-xylene and isoprene. The oxidation of these produces peroxy radicals which can lead to ozone formation through NO to NO2 conversion. We have investigated the importance of the loss route for these radicals via the reaction: peroxy+HO2=hydroperoxide+O2 where the hydroperoxides can be removed through dry or wet deposition. We show that the neglect of hydroperoxide formation leads to the significant overestimation of free radical concentrations.

MEASUREMENT OF HO_X IN THE MARINE BOUNDARY LAYER

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An instrument to detect atmospheric concentrations of the hydroxyl (OH) and hydroperoxyl (HO_2) radicals has been developed using the FAGE (fluorescence assay by gas expansion) technique. The instrument monitors the OH radical via on-resonance laser-induced fluoresence (LIF) spectroscopy of the $A^2\Sigma$ (v' = 0) - $X^2\Pi_i$ (v'' = 0) transition at 308nm. Ambient air is expanded through a 1mm nozzle to low pressure where it is irradiated by the laser pulse at a repetition rate of 7kHz, with the resultant flourescence being detected by gated photon counting. HO_2 is monitored by chemical conversion to OH by the addition of NO, with subsequent detection using LIF. Detection limits of 5 x 10^5 and 2.5 x 10^6 molecule cm^{-3} (signal to noise ratio of 1, integration time of 150s) for OH and HO_2 respectively, were determined by laboratory and field calibrations. The instrument was deployed in the marine boudary layer at Mace Head, Eire, during April and May of 1997 as part of the ACSOE field campaign. Selected results will be presented at this conference.

MEASUREMENTS OF NITRATE RADICALS AND ESTIMATION OF PARTICLE SURFACE AREA AT CAPE ARKONA (RÜGEN ISLAND)

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Long-path Differential Optical Absorption Spectrometer (DOAS) measurements of nitrate radicals were carried out in the marine boundary layer at the rural site Arkona. Observations between April 1993 and September 1995 cover a period of nearly 30 months. The mean NO_3 concentration refers to the night time averages for summer and autumn fluctuate between 7 and 10 ppt. Particulate extinction measurements in the wavelength region from 320 nm to 680 nm have been performed by means of a DOAS system. This allows a rough estimate of the particle number concentrations from about 100 cm^{-3} to several 1000 cm^{-3}, and of the mean surface area concentration from about 350 $\mu m^2/cm^{-3}$ during summer 1995. The calculated NO_3 and N_2O_5 lifetime versus the particle surface area concentration derived from DOAS measurements for summer 1995, confirm that the maximum lifetimes increase with smaller aerosol surface concentrations. On the one side, the upper limits for the NO_3 and N_2O_5 lifetimes give evidence for the limiting case of radical loss exclusively by reactions on the aerosol surface. On the other hand, it is clear that at most times other loss processes are dominant yielding considerably smaller lifetimes. This can be due to homogeneous gas phase reactions. An investigation of NO_3 night time variations and an assignment of the lifetime determining processes from additional meteorological and chemical information will be presented.

VOLATILE ORGANIC COMPOUNDS AND PEROXY RADICALS CONCENTATIONS FOR URBAN AND RURAL REGIONS OF RUSSIA

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The results of measurement of volatile organic compounds (VOC) concentrations in different urban and rural regions of the European part of Russia and Siberia got at the moving laboratory along the main line «Moscow-Vladivostok» are presented in the report. The content of alkanes, alkenes, aldehydes and agents of the other groups of hydrocarbons and their reactants (total 45-65 agents) in air samples picked in the sorbtion tubes was determined. VOC content and their character interrelation for rural regions give possibility to separate some areas: European, West Siberia, South Siberia, and East Siberia. VOC concentration in urban air depend on local pollution sources. On the base of trajectory analysis method the attempts to allocate the VOC sources were made.
At the same time in these regions were made the measurements of O_3, NO_x and UV radiation fluxes. On the base of these data concentration of peroxy radicals was estimated. For the some regions (Moscow and others) the analysis of minor constitutes concentrations behaviour in dependence on the industrial stress was made. Comparison of VOC and peroxy radicals distribution features shows the relation between them and characterizes oxidative atmosphere ability under different conditions. Using peroxy radicals as the trace compound of atmosphere pollution is discussed.

MEASUREMENTS OF PEROXY RADICAL CONCENTRATIONS IN A PERI-URBAN ATMOSPHERE USING THE CHEMICAL AMPLIFIER METHOD

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Peroxyl radical concentrations have been measured at a site located 10 km downwind from Orléans during two weeks in July 1997. The measurements were performed using the chemical amplifier instrument developed at CNRS. The amplification was obtained from the $RO_2/NO/CO$ system. and the NO_2 produced was measured by chemiluminescence of luminol. The daily variations of RO_2 concentrations were measured together with those of ozone and NO_x (NO. NO_2). The NO_x concentrations ranged from a few ppbv to 15 ppbv and ozone maxima of 70 - 80 ppbv were observed almost every day. The daily profiles of RO_2 concentrations showed maxima from a few tens to 100 pptv during daytime with non-zero concentrations sometimes observed during nighttime. The maxima of RO_2 concentrations always appeared before those of ozone. These observations will be discussed referring to the current knowledge of the photochemical pollution.

TROPOSPHERIC OH BOX-MODELLING AND ANALYTICAL STUDIES: COMPARISON WITH OBSERVATIONS FROM THE WAOSE`95

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Data of the most tropospheric relevant trace gases, collected in June 1995 during the Weybourne Atmospheric Observatory Summer Experiment (WAOSE´95), were used to box-model the concentration of the free radicals playing a prominent role in the oxidising capacity of the atmosphere. The observatory (TOR Station No. 7) can be characterised by a clean atmospheric environment that occasionally is influenced by anthropogenic emissions of the industrial region in the central UK. The box-model was constrained to observations and is based on the gas phase reactions of the *regional acid deposition model (RADM2).* The calculations were compared with in-situ measurements of the OH radical concentration taken by the Multipass Optical Absorption Spectroscopy (MOAS) system. Its temporal and spatial resolution of 1 minute and 6 m, respectively, together with the extended input into the model provides a well suited opportunity for testing the actual theory of atmospheric chemistry. Agreement of theory and experiment for most part of the campaign is given, but deviations exist.

LABORATORY STUDIES ON THE SELECTIVE MEASUREMENT OF ORGANIC PEROXY RADICALS AND HO_2 BY CHEMICAL CONVERSION/ ION MOLECULE REACTION MASS SPECTROMETRY

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Results of recent field and laboratory studies which were conducted with a novel method for groundbased and aircraft-based measurements of peroxy radicals will be presented. The main characteristics of this method developed at our laboratory are chemical conversion and amplification of peroxy radicals to sulfuric acid and detection of H_2SO_4 by ion molecule reaction mass spectrometry (IMRMS). One part of the studies aimed at the calibration of the instrument and diagnostic investigations on interference and loss processes and conversion efficiency. Further laboratory works focused on the discrimination between organic peroxy radicals and HO_2 to develop an HO_2-only measuring mode of operation and on the conversion efficiency of organic peroxy radicals to HO_2.

A QUALITY CONTROL / QUALITY ASSESSMENT METHOD FOR ATMOSPHERIC NON-METHANE HYDROCARBON (NMHC) MEASUREMENTS

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Reactive hydrocarbons plays a crucial role in the chemistry of free radicals in the atmosphere. The processes cannot be studied without reliable. representative hydrocarbon concentration data. Having an existing data set of atmospheric NMHC measurements the types of compositions can be defined by cluster analysis. The types are site specific and may depend on the season. on the air mass sampled. its trajectory and chemical age. as well as on other factors. Analysing all the conditions of the measurements those type(s) can be selected which represent(s) the background conditions at the given site. Samples in the other clusters may be non-representative for the background conditions due to the special atmospheric conditions. sampling or analytical errors. Any new air sample can be accepted as representative for the background conditions if its composition falls into one of the selected clusters. The presentation discusses the NMHC measurements from K-puszta. Hungary. for the illustration of the method. It also presents the treatment of the partially analysed samples.

ON THE DEPENDENCE OF THE OH RADICAL CONCENTRATION ON ITS PRECURSORS: RESULTS OF THE POPCORN FIELD CAMPAIGN

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The extensive OH data set recorded during the POPCORN campaign at a rural site in north-eastern Germany in August 1994 was investigated to reveal the dependence of the concentration of OH radicals on its precursors. RADM-2 model calculations and an empirical analysis of the measurement data show that for typical POPCORN conditions the OH concentration was rather insensitive towards variations in the concentrations of most trace compounds. In particular variations in ozone and formaldehyde concentrations had only little influence on OH. The dependence of OH on NO_x could clearly be extracted from the data, showing that OH concentration peaks at 1.5 ppb NO_x and declines towards higher and lower NO_x concentration. Nevertheless, on average for this data set, variation in the NOx concentrations accounts for only 6% of the total OH variability, while variation of photolyses frequencies accounts for 71%. The combination of empirical analyses and model calculation was found to be a skillful method to verify functional connections of concentrations of atmospheric chemical constituents as predicted by the model calculations

PRODUCTION AND DESTRUCTION RATE OF OH AT AN ISLAND AND A SUBURBAN SITE IN GREECE DURING THE 1996 PAUR CAMPAIGN

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During the 1.-15. June 1996 PAUR campaign, concurrent ground measurements of O3, J(O[1D]), humidity, temperature and C4-C12 hydrocarbons have been performed at an island and a suburban site in Greece. The measurements allowed for the calculation of OH production rates, POH, as well as relative destruction rates for the OH reaction with the measured hydrocarbons. Due to the relatively high ozone and irradiance values, daily peak production rates of OH were around 8X106 molecules cm-3 s-1. During most of the days, OH production rates were at the island site higher than the ones at the suburban site, on one case by up to 100%. On at least two days, though, the opposite was true, with OH production rates being at the suburban site around 25% higher than at the island site. A two-days case study is presented, where the observed production rates are discussed in relation with concurrent BREWER measurements of total ozone and LIDAR measurements of aerosol vertical distribution.

OH RADICALS IN THE ATMOSPHERE

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OH is the main oxidizing agent in the troposphere. It reacts with most trace gases, often as the first and rate limiting step in the oxidation mechanism. Thus OH controls the atmospheric lifetime and therefore the concentration of many anthropogenic pollutants and natural trace gases. For about two decades our knowledge about the role of atmospheric OH mainly came from laboratory investigations, modelling studies, or field experiments which yielded indirect evidence of tropospheric OH. Direct observational data on atmospheric OH were scarce due to the technical difficulty of measuring the extremely small concentration of ambient OH. In the last few years the situation has greatly changed since a number of different and promising OH measurement instruments have become operative. The new techniques have yielded exciting observations of OH in a number of different environments on the continent, in coastal areas, on the free ocean, and the free troposphere. This presentation aims to give an overview of this rapid development which has opened new possibilities to study the photochemistry of the atmosphere.

AIRBORNE MEASUREMENTS OF THE ABSOLUTE SOLAR ACTINIC UV FLUX AND THE $O_3 \rightarrow O(^1D)$ PHOTOLYSIS FREQUENCY IN THE TROPOSPHERE BETWEEN 0-12 KM ALTITUDE.

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Spectra of the absolute solar UV actinic flux $F_\lambda(\lambda)$ were measured in the troposphere on-board the DLR Falcon research aircraft over the Aegean Sea in June 1996. The measurements were performed with a dual channel scanning spectroradiometer, equipped with two optical input systems pointing to the zenith and the nadir, respectively. The spatial sensitivity of each individual optical input system was adjusted to be nearly uniform over one hemisphere (2π sr). Thus, the two measurement channels detected the downwelling and upwelling component of the solar actinic flux $F_\lambda(\lambda)$, respectively.
In this work, we present measured vertical profiles of the actinic flux from 290nm - 420nm between ground level and the tropopause. Vertical profiles of the integrated UV-A and UV-B actinic radiation and the $O_3 \rightarrow O(^1D)$ photolysis frequency $J(O^1D)$ calculated from the measured spectra of $F_\lambda(\lambda)$ are shown. The shape of the vertical profile of $J(O^1D)$ is discussed with respect to variations of the actinic flux with altitude and the temperature dependence of the quantum yield $\phi(O^1D)$ from the $O_3 \rightarrow O(^1D)$ photolysis.

INFLUENCE OF THE UNCERTAINTY OF GAS PHASE RATE CONSTANTS ON THE MODELED TROPOSPERHIC OH CONCENTRATIONS

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The rate constants of some important reactions used for atmospheric chemical models are known only with considerable uncertainties of about 10 - 50 %. For example, the rate constant for the reaction of OH with NO_2, which is a very important sink of OH in the troposphere, might be overpredicted by 10 - 30 % at room temperature. Also a revised rate constant for the formation of OH in the reaction of HO_2 with NO has been reported.
Numerical simulations of the OH concentration using experimental data of the POPCORN campaign are presented. The calculations with a simple box model are based on the chemical mechanism RADM2 from the Regional Acid Deposition Model. Some important rate constants are varied and the influence on the calculated OH concentration is presented.

THE EFFECT OF HUMIDITY ON WALL LOSS AND CHAIN LENGTHS IN RADICAL AMPLIFIERS.

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Radical amplifiers involve ambient radicals in a chain reaction with added NO and CO. The length of this chain, the amplification, is determined by the relative rates of the propagation and termination reactions. In most instruments the major chain termination reaction is the loss of peroxy radicals to the walls of the reactor. Since ambient measurements are made under more humid conditions than calibrations and the ambient humidity can change markedly during a day, laboratory studies to investigate the effect of humidity on both the rate of radical loss to the reactor walls, and its impact on the chain length of the detector have been undertaken. The first-order rate coefficient for radical loss to the reactor walls is found to increase with increasing humidity. The chain length of a typical radical detector used in field studies is found to decrease with increasing humidity. A model has been used to reconcile the observed chain lengths with the varying termination rates. The impact of these results on field measurements is discussed.

ISOPRENE AND RADICALS: STIMULANTS FOR THE EXPORT OF CONTINENTAL OZONE ?

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Biogenic hydrocarbons have long been recognised as a potentially important source of peroxy radicals in the atmosphere owing to the nature of their rapid reactions with the primary atmospheric oxidants. Peroxy radicals produced in oxidative processes in the atmosphere can be responsible for significant daytime *in-situ* production of ozone *via* their *catalytic* oxidation of NO to NO_2. Ozone production is a non-linear process and dependant on a number of factors including the availability of NO_x, VOC and HO_x. There seems to be two distinct views as to the role of the biogenic hydrocarbon isoprene in the production of ozone. The first is that if HO_x production is predominately controlled by ozone photolysis then isoprene will have little effect. The second is that isoprene even at the level of a few 10's of pptv may have a significant effect on ozone production. Data from ACSOE-OXICOA EASE96 campaign at Mace Head in Ireland is used to illustrate that during a period dominated by semi-polluted air of UK and European origin, that the biogenic molecule isoprene can play an important role in the production of peroxy radicals and subsequently ozone. Using both measurements and models it has been demonstrated that isoprene can undertake both a direct role in the production of HO_x and an indirect role in the control of NO_x. The sum of these effects has wide implications for the export of regional pollution from urban areas to the background atmosphere.

THE IMPORTANCE OF NITRATE RADICALS FOR ATMOSPHERIC CHEMISTRY.

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Nitrate Radicals (NO_3) react with many organic compounds (VOC) and thus initiate their degradation. In addition they lead (via N_2O_5 formation) to the conversion of NO_X to HNO_3, thus promoting the removal of NO_X from the atmosphere. The much smaller reactivity of NO_3 towards VOC (by several orders of magnitude) compared to OH radicals can be offset by the much higher abundance of NO_3 in many areas. For instance NO_3 can be an important sink of DMS in the marine environment, while at the same time changing the NO_X - NO_Y ratio there.
An interesting feature is the nearly exclusive formation of NO_3 by reaction of NO_2 + O_3, which - in contrast to most OH source mechanisms - proceeds without sunlight. Thus NO_3 - reactions lead to nighttime RO_2- (and even OH) formation.
The contribution of NO_3, in particular during times of low insolation, to the oxidation capacity of the atmosphere and its role in NO_X-removal is discussed in the light of recent findings on the average NO_3 concentration and its vertical distribution in the atmosphere.

AIRCRAFT-BORNE MEASUREMENTS OF PEROXY RADICALS, RELATED TRACE GASES, AND UV RADIATION

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We have carried out aircraft-borne measurements of peroxy radicals, related trace gases, and UV radiation at altitudes between 3.7 and 7.8 km. Peroxy radicals were measured by chemical conversion to gaseous sulfuric acid and detection of sulfuric acid by ion molecule reaction mass spectrometry. The peroxy radical instrument was calibrated and thoroughly characterized by in-flight and laboratory diagnostic measurements. Results of diagnostic measurements as well as results from the measurement flights will be presented and discussed.

INVESTIGATION OF THE EFFECTIVE ABSORPTION CROSS-SECTIONS OF WATER VAPOUR AND OXYGEN FOR THE VUV EMISSION OF LOW PRESSURE MERCURY LAMPS AT 185 NM

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The photolysis of water vapor in air by the 185 nm radiation of a low pressure mercury lamp is a widespread HO_x source for calibration of field instruments that measure atmospheric OH and HO_2 concentrations. The determination of the generated radical concentration depends critically on the correct value of the H_2O absorption cross-section at 185 nm. If the photon flux is monitored by O_2/O_3 chemical actinometry, the effective O_2 absorption cross-section (σO_2) must also be known accurately. Following a recent experimental study of Lanzendorf et al. we have reinvestigated the absorption of the 185 nm Hg-lamp radiation by O_2 and H_2O for the conditions used in the HO_x calibration of our LIF-instrument in Jülich. We present typical VUV emission spectra of several Hg lamps measured with a VUV spectrometer at high spectral resolution of 0.01 nm and 0.05 nm. These measurements clearly demonstrate that the 185 nm line has an individual spectral shape for each lamp and exhibits a long tail towards wavelength up to 200 nm. The different overlap with the O_2 Schumann-Runge absorption lines results in different σO_2 values for each lamp as well as in different dependencies of σO_2 on the O_2 column. We also present new measurements of the effective absorption cross-sections of H_2O at 185 nm which will be compared with other recent literature values.

ON THE STATUS OF PEROXY RADICAL MEASUREMENTS: RESULTS FROM THE PEROXY RADICAL INTERCOMPARISON EXERCISES I+II

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Peroxy radicals (HO_2 and its organic homologues, RO_2) are the key intermediates in the oxidative decomposition of CO and hydrocarbons and in the formation of photo-oxidants such as ozone, PAN and other organic nitrates, and peroxides. Measurements of peroxy radicals thus provide important insight into the fast photochemical cycles in the atmosphere. Measurements of peroxy radicals have been reported using Matrix Isolation/ESR-spectroscopy (MIESR), Laser Induced Fluorescence (LIF), and Chemical Amplification (CA).
This contribution will discuss the findings from two international exercises (PRICE and PRICE II) which were concerned with the comparison of the different techniques for peroxy radical measurements. Emphasis of PRICE was the comparison of MIESR and several CAs in the atmosphere, whereas PRICE II was mainly concerned with obtaining a better understanding of the particular problems associated with the chemical amplifier, e.g. detection efficiency for RO_2 versus HO_2, and the various radical sources that are used for calibration of the CA.
[2] M. Heitlinger, F. Holland, A. Hofzumahaus, D. Mihelcic, P. Müsgen, M. Weber (FZ-Juelich); J.P. Burrows, M.D. Andres Hernandez, D. Stöbener (Univ. Bremen); D. Perner, T. Arnold, R. Seuwen (MPI-C Mainz); C.A. Cantrell (NCAR, Boulder); S.A. Penkett (Univ. East Anglia, Norwich); K.C. Clemitshaw (Imperial College London); G. Laverdet, K. El-Boudali, S. Teton (CNRS Orlans); J. Hjorth, O. Poulida (JRC Ispra); D. Hastie, M.C. Arias (York Univ., Toronto); P. Borrell, and P.M. Borrell (IFU, Garmisch-Partenkirchen)

THE MEASUREMENT OF TROPOSPHERIC HO_2 RADICAL CONCENTRATIONS BY LASER-INDUCED FLUORESCENCE AT LOW PRESSURE

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Photochemical oxidation of most natural and anthropogenically produced atmospheric trace gases is initiated by reactions with hydroxyl radicals (OH) and leads to the formation of hydroperoxyl radicals (HO_2). While in the last years a number of high quality OH data sets have been obtained by different measurement techniques, reliable HO_2 measurements are still sparse. In order to measure both radicals in parallel with a high time resolution we have extended the capabilities of our current OH laser-induced fluorescence instrument by adding a second measurement channel for the detection of HO_2 radicals. While this instrument directly detects OH radicals, HO_2 radicals have first to be converted into OH by reaction with NO. In order to quantify the HO_2 measurements not only a thorough understanding of the chemical conversion step inside the fluorescence chamber and its influence on the detection sensitivity is needed but also a well characterized HO_2 radical source has to be available for the calibration of the instrument. In our presentation we will describe the experimental setup of the HO_2 channel and will discuss several experiments which were performed in order to arrive at a comprehensive understanding of the different mechanisms underlying the successful measurement of HO_2 radical concentrations by LIF spectroscopy.

OA20 Radiogenic isotopes as tracers of source-areas for aerosols, suspended matter and sediments (co-sponsored by ST)

Convener: Grousset, F.E.
Co-Convener: Sirocko, F.

TRACKING PARTICLES AND PARTICULATE PROCESSES WITH RADIOGENIC ISOTOPE TRACERS

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The processes by which minerals become detached from parent rocks and each other, become ground down, partly dissolved and transformed into other minerals, are transported by moving water, wind and ice to intermediate and final places of deposition on the continents and in the oceans -- these processes reflect an enormous range of physical and chemical conditions of the Earth's surface and of its fluids of air and water. To decipher the record of these processes and conditions from sediments generally requires that they be traceable back to the primary rocks from which they were derived. Tracer characteristics for this determination of provenance must be, at least in combination, diagnostic of the source area and must be reasonably conservative throughout the intervening processes to their ultimate deposition. Natural isotope compositions of several radioisotope systems provide excellent tracer characteristics because they vary with the lithologies and geologic ages of parent rocks, which themselves vary on spatial scales comparable to those of the physical and chemical processes elucidated. The geochemistries of the several radioisotope systems react differently to these weathering and transport processes. We will review the several decades of use of these isotope systems (Rb-Sr, Sm-Nd, U-Pb) by the authors and others to study marine, lacustrine and soil sediments and modern aerosols as well as the record of paleoaerosols in polar ice cores and snow.

GCM MODELING OF ATMOSPHERIC DUST TRANSPORTATION WITH CONSTRAINS ON PALEO SOURCES

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From measurements of radiogenic isotopes it has been possible to put certain limits on the location of the possible sources of mineral dust transportated to the polar ice caps during the Last Glacial Maximum. We here present the results of simulating the atmospheric dust cycle in an atmospheric general circulation model. The results of the model were compared to results from measurements of radiogenic isotopes in dust from the ice cores and potential source areas. Model results for the Last Glacial Maximum, in consistance with measurements, show a strong transportation of dust from Patagonia to the Antarctic ice sheet. For the Greenland ice sheet the situation is somewhat more complicated due to the proximity of several potential source areas. However the measurements provide constrains on the sources of eolian dust, which are most important for the simulation of dust transportation in a paleo-environment, where information on e.g. vegetation and soil texture are rather scarce.

Sm/Nd ISOTOPES IN CONTINENTAL AEROSOLS: RESULTS FROM A STUDY OF EPIPHYTIC LICHENS

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Epiphytic lichens hanging in trees provide a natural means of filtering atmospheric particles over large geographic areas. Concentrations of non-soluble elements in these particles are found in ratios comparable to those of continental crustal sediments. We report Sm/Nd isotopic results from lichens collected in Europe and N. America, where geological terrains range in age from Archean to Cenozoic. This large age variation permits the aerosol sources to be easily traced by their Nd isotopic compositions. Additionally it allows us to investigate whether trace element ratios of aerosols have varied with crustal residence age, estimated from the Nd isotopic composition. Our preliminary data display a range in $^{147}Sm/^{144}Nd$ that varies from 0.096 to 0.121 and correlates with a range in Nd model age from 2.7 Ga to 1.5 Ga. These ages are consistent with the geological ages of the terrains in which the lichens were collected. The observed correlation agrees with that found among river sediments in previous studies (Goldstein et al., 1984; Goldstein and Jacobson, 1988). We find no correlation between major element composition, as expressed by Ti/Al ratio, and Nd model age. This suggests that the observed trend does not result from mixing between young mafic and old felsic endmembers, but rather reflects secular variation of trace element ratios derived from the mantle (Albarede and Brouxel, 1987).

ORIGIN OF CONTINENTAL AND VOLCANIC AEROSOLS OF THE VOSTOK ICE CORE (ANTARCTICA)

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The Vostok ice core (East Antarctica) provides a continuous record of continental dusts (2-3 µm) and volcanic tephra (<50 µm) which have undergone tropospheric transport (5000 to 8000 km) and have reached the austral ice cape, during the last four climatic cycles.
For continental dusts, analyses of Sr and Nd isotopes show that they come from Patagonia during both glacial (fluxes of 20 mg/m^2/year) and interglacial periods (fluxes of 1.5 mg/m^2/year). For volcanic ash layers, the combination of Sr/Nd, REE, major and trace elements informations, permits to identify, among the Antarctic and peri-Antarctic volcanic provinces, four main volcanic sources: South Sandwichs Islands, Antarctic Peninsula, Southern Volcanic Zone of South America and Marie Byrd Land in West Antarctica.
Those results show that continental and volcanic aerosols are transported from aereas located, at mid and high latitudes, on the atlantic side of Antarctica, into East Antarctica. This westerlie circumpolare current, with a convergent component toward Antarctica, exist both during glacial and interglacial periods. This reconstruction of large scale paleo-atmospheric circulation permit a better definition of the location and the geomorpholgy of continental dust sources and give new constraints to Atmospheric Global Circulation Models.

SAHARAN WIND REGIMES TRACED BY THE Sr-Nd ISOTOPIC COMPOSITION OF THE SUBTROPICAL ATLANTIC SEDIMENTS.

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New Nd-Sr isotopic data on the <30µm lithic particles of surface and LGM sediments recovered along the African margin between the equator and the Gibraltar Strait, are presented in combination with grain-size measurements. This <30µm size fraction allows us to eliminate any hemipelagic contribution that could occur in the coarser fractions. In the eolian fraction, both Sr and Nd isotopic tracers reveal the same major northwestern origin (Mauritania, Mali, southern Algeria and Morocco). The Archaean formations of the western Saharan shield could be the source of the very unradiogenic ratios observed here. The more southern regions (Senegal, Guinea) act only as secondary sources. A similar pattern is observed for the LGM. Lithic particles are mostly transported by both Trade and Saharan Air Layer (SAL) winds, along an average NE-SW axis; this main feature matches the "southern plume", characterizing the dust transport observed during winter. No significant latitudinal shift of the belt winds is observed between LGM and today. At LGM, however, dust fluxes were 2 to 4 times higher than today, leading to a more "Archaean-type" imprint in the deposits. We do not observe any clear relationship between the latitudinal variability of the upwelling systems identified at LGM, and the location of the major wind systems. Both enhanced aridity on the continent, and increased wind speed probably occurred together over western tropical Africa at LGM.

K-Ar AND $^{40}Ar/^{39}Ar$ ISOTOPIC SIGNATURE OF ENHANCED ICE-RAFTING SUPPLY IN THE NE ATLANTIC.

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Mineralogical, K-Ar and $^{40}Ar/^{39}Ar$ age determinations were carried out on fine grained (<16 µm) silicate fractions of NE Atlantic sediments (47°30'N - 19°30'W) to characterize the changes in source and transport of detrital supply during the phases of enhanced ice-rafting (Heinrich events) of the Late Quaternary. HL_1, HL_2, HL_4, HL_5 (and two older HLs) sediments display equivalent K-Ar and integrated $^{40}Ar/^{39}Ar$ ages within analytical uncertainity which suggests a mixture of Grenvillian (800-1000 Ma) and lower Proterozoic (1800-2100 Ma) minerals originating from the Canadian shield. HLs do not consist in a simple addition of coarse ice-rafted material to ambient sedimentation. In contrast $^{40}Ar/^{39}Ar$ integrated ages are systematically older than K-Ar ages for ambient and HL_3 silicate fractions. The age discrepancy is due to recoil induced ^{39}Ar loss attributed to a volcanogenic component either transported by NADW from the Iceland-Faeroe regions for ambient sediments and/or ice-rafting for HL_3. This component is nearly absent for HL_1, HL_2, HL_4 and HL_5. The isotopic data support the hypothesis of a strong decrease of deep water circulation due to surges of the Laurentide ice sheet in the NE Atlantic basin. However, information on changes in deep water circulation mode during HL_3 cannot be inferred from K-Ar and $^{40}Ar/^{39}Ar$ isotopic data.

PROVENANCE OF CLASTIC SEDIMENTS IN THE NORTHERN INDIAN OCEAN: EVIDENCE FROM THE $^{143}Nd/^{144}Nd$, $^{87}Sr/^{86}Sr$ COMPOSITION

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Distribution patterns of $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ for the lithic fraction of Arabian Sea sediments are presented for the sediment surface, the early Holocene and the late Glacial. The Holocene patterns outline a prominent source of dust by northwestely winds from the Arabian peninsula, which dominates sedimentation in the western sector of the Arabian Sea, and a fluvial source by Indian rivers in the eastern sector. During glacial times we observe a third eolian source with dust plumes entering the Arabian Sea from the northwest, i.e. from Iran and the area of the Persian Gulf, which was dry land at that time. Dust raised in East Africa and transported by the low level summer southwest monsoon is not observed and the isotopic composition of sediments in the western Arabian Sea is far from values being typical for the East African basalts. Accordingly, past variations in the composition and mass of eolian particles deposited in the western Arabian Sea are related to climate changes; the dust is not transported directly by the southwest monsoon winds, but by northwesterlies, thus recording environmental changes in the entrainment areas of dust, sea level, and latitudinal shifts of the boundary between the southwest monsoon wind over the ocean and northwesterly winds over the desert.

STABLE LEAD ISOTOPES CONTRIBUTION TO THE CHEMICAL CLIMATOLOGY OF THE WESTERN MEDITERRANEAN

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Our main objective is to discriminate source inputs from various anthropogenic (industrial, gasoline exhausts) and natural (mostly Saharan dust) emissions to the western Mediterranean to better define the chemical climatology of this enclosed basin. Here we present the first evidence of a clear isotopic discrepancy between anthropogenic emissions from southern France, Spain, Italy and Morocco. This discrepancy is investigated on the basis of gasoline and industrial isotopic signatures as measured in western Europe. Isotopic ratios were determined on aerosols collected concurrently from a French coastal site (Cap Ferrat near Nice) and at sea (transect between Dakar-Senegal and Toulon-France). The $^{206}Pb/^{207}Pb$ ratios appear more radiogenic at sea (=1,155±0,017) than on the coast (=1,137±0,02) suggesting a larger impact of the Saharan dust at sea. Stable lead isotopes were determined from sequential atmospheric sampling (aerosols, filtered and unfiltered rain, bulk deposition) at the Cap Ferrat during specific climatological events (including Saharan dust and anthropogenic plumes) to investigate this difference and trace the processes that control trace metal deposition to fragile coastal environments.

ON THE ORIGIN OF CONTINENTAL DUST IN THE GREENLAND GRIP ICE CORE BACK TO 44 KYR BP

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Fourteen dust samples extracted from the GRIP ice core (72.6N, 37.6W) [A] have been characterized in terms of mineralogy, Sr, Nd, and Pb isotopic composition, and REE concentrations. The ice samples are taken from the Holocene and from both mild and cold periods during the Last Glacial back to 44 kyr BP. The objective of the study is to determine the variability of the dust composition in relation to climate, and to determine the continental provenance of the dust. The overall mineralogy and the Sr and Nd isotopic composition is similar for all samples, but with some variation in the Holocene. A comparison with samples from possible source areas confirms Asia as being the main source area during the LGM [B]. Preliminary results indicate that Asia is also the dominant source area at other times during the Last Glacial and the Holocene, but with a possible addition of another probably-Asian source in the Holocene.

[A] Dansgaard W. et al., Nature 364, 218-220 (1993)
[B] Biscaye P.E. et al., JGR, 102, C12, 26765-26781 (1997)

PARTICLE GRAIN-SIZE CONTROL ON THE Sr-Nd AND Pb ISOTOPIC COMPOSITION

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One of the most direct sources of information on paleo-atmospheric circulation is provided by aerosols raised from the continents by dust storms and transported over long distances to the polar ice caps. The clay mineralogy and radiogenic isotopic characteristics of the dust accumulated in GISP 2 ice core (Greenland) and Vostok ice core (Antarctica) have allowed us to identify their origin, from which we can construct the trajectory of the paleo-atmospheric circulation. To use the lithic particles as tracers of the source-areas, it is assumed that their isotopic signal have not undergone chemical and petrological modifications during the phase of deflation, transporation and deposition. To try to answer this particular point, we have studied the relationship between clay mineralogy/Sr-Nd-Pb isotopic system and grain-size fraction of atmospheric dust particles, sampled in possible source areas from around both hemispheres. The systematic analyses of Sr-Nd-Pb isotopic ratios measured on separate size fraction (0-2µm, 2-5 µm, 5-10 µm, 10-20 µm, >20µm) reveal high isotopic variations related to the grain size fraction. The variations for the Rb-Sr system follow the same trend, which can be explained by a mineral partition in the parent rock and a preferential alteration of the 86Sr-rich, 87Rb-poor feldpar in many crustal rocks. For the Sm-Nd and U-Th-Pb systems, the isotopic variations are more diverse and seem to be related to mineral fractionation related to the size.

REE PATTERN AND ND ISOTOPIC RATIOS OF SEAWATER, FILTERED SUSPENSIONS AND TRAPPED MATERIALS FROM TROPICAL NE ATLANTIC

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Rare Earth Element (REE) concentrations and Nd isotopic ratios were measured for seawaters, filtered suspensions (> 0.65 µm) and trapped materials collected at three EUMELI sites (F-JGOFS: 20°N, 18 ~ 31°W). The $\varepsilon_{Nd(0)}$ values of the seawaters vary with depths and sites (-13.0 ~ -10.5). Those of the suspensions present vertical profiles similar to those of the seawaters, although the $\varepsilon_{Nd(0)}$ values are more negative (-13.5 ~ -11.7). Mean $\varepsilon_{Nd(0)}$ values of carbonate free sediments are more negative than the suspension values at the studied sites (Grousset at al., in press). The intermediate values of the suspensions suggest that the suspended matter contains both authigenic (seawater origin) and lithogenic Nd. Light REE enriched REE pattern of the suspensions supports a preferential uptake of dissolved LREE by the marine particles. Applying the binary mixing hypothesis to the trapped materials, we estimate that 40 ~ 45 % Nd in the large sinking particles is seawater origin. Our results show that the marine particles contain inert lithogenic Nd which allows to trace lithogenic sources. However, they transport also authigenic Nd signals resulting from a surface adsorption and dissolved-particle exchange.

OA20

OA21 Biogeochemical interactions in the coastal marine environment

Convener: Monaco, A.
Co-Convener: Price, N.B.

ANTHROPOGENIC LEAD AND ^{210}Pb AS INDICATORS OF PARTICLES RESUSPENSION IN THE GULF OF LIONS.

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Lead concentrations, stable isotope compositions and ^{210}Pb activities were measured in cores and sediment trap samples collected on the continental margin of the Northwestern Mediterranean Sea. Variations of isotopic composition between coastal and open ocean sites implies different sources of lead in the particles. On the Gulf of Lions slope, resuspension processes are demonstrated by comparing the anthropogenic lead flux in sediment-traps with the inventories in the sediment. Resuspension of particles bearing anthropogenic lead is the main source for the trap material (up to 100%) and decreases from the shelf-break to 1000 m depth in the Planier and Lacaze-Duthiers canyons. This process also explains the focalisation of ^{210}Pb at these sites, evidenced by ^{210}Pb fluxes in the traps higher than the total input from the atmosphere and the *in situ* production in the water column.

HYDROCARBONS IN THE BOTTOM SEDIMENTS OF THE KANDALAKSHA GULF OF THE WHITE SEA.

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Data of hydrocarbon distribution in the one of the largest gulfs of the White Sea - Kandalaksha Gulf are presented. These measurements were carried out near the Kandalaksha port. The basic part of alkane-naphtene hydrocarbons (HC) is accumulated in thin pelite silts in deep-water parts of the Gulf, and also in its small bays. The HC content in the top layer (0-5 cm.) of the bottom sediments varies from 43.8 mkg/g up to 305.7 mkg/g of a dry deposit or from 1of Corg varies from 0.28composition of n-alkanes is anoxic conditions in bottom sediments owing to accumulation of a large part of terrigenous organic matter in the top layers of modern bottom sediments. Oil pollution in the surface layer of bottom sediments in a section from the oil-station to the open part of the Gulf has been found. Analysis of the n-alkane composition shows that the major proportion of the organic matter has terrigenous origin and a high degree of its transformation in the processes of sedimentation. Antropogeneous polluting substances are accumulated in the poorly washed out bays of the Gulf.

HIGH-RESOLUTION MICROELECTRODE PROFILES OF REDOX SPECIES IN SEDIMENT PORE WATERS

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Using a voltammetric Hg/Au amalgam microelectrode on undisturbed sediment cores from Laurentian Trough in the Gulf of St. Lawrence, we have measured the vertical distributions of O2, Mn(II), Fe(II) I(-I), and HS(-I) with millimeter resolution in the top several cm of the cores. The distributions of NO3-, NH4+ and HPO4- were measured colorimetrically, with a vertical resolution of 5 mm, using porewater samples obtained by conventional slicing and centrifugation techniques of replicate cores. Solid-phase Mn in these cores was extracted with HCl and measured with AA-spectrophotometry. Benthic fluxes of O2, NO3- and HPO4- were measured by incubating cores at the in-situ temperature.
The vertical distributions we measured were qualitively similar at the three studied sites. In all cores, O2 disappeared at about 4 mm depth, followed by the successive appearance of I(I-), Mn(II) and Fe(II). Our data are consistent with the paradigm of successive use of electron acceptors during organic carbon degradation according to free energy yield, but they also reveal new reactions involving secondary reactants. Thus nitrate and iodate are reduced by Mn(II); denitrification occurs immediately below the sediment-water interface there is new nitrate production below this depth by an unknown suboxic nitrification process.

PARTICULATE LIPIDS AS BIOGEOCHEMICAL INDICATORS OF ORGANIC MATTER TRANSFORMATION IN ARCTIC SEAS

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Lipid composition of suspended particles from the southern part of the Kara Sea (Ob River–Kara Sea transect) and from the transectional zone between Kara and Laptev Seas was used to investigate the features of organic matter origine and transformation in Arctic seawater environment. The analysis of 7 lipid classes (hydrocarbons, polar lipids, sterol esters, wax esters, fatty acid esters, triacylglycerols and free fatty acids) on Iatroscan device indicates that hydrocarbons and polar lipids are the main components of the lipid composition within Kara and Laptev seas. The allocation of the studied lipid classes demonstrates strong spatial variability. The distribution of major lipid classes in the southern part of the Kara Sea is mainly related to the influence of the Ob River input. The allocation of lipid concentrations , in particular of triacylglycerols, within transitional zone between Kara and Laptev Seas is connected to the sea-ice margin position. The highest triacylglycerol concentrations near the ice edge reflect the increasing phytoplankton growth induced by the melting processes. The distribution of total lipid concentrations and polar lipid contents within water column demonstrates the influence of allocation of the main water masses, in particular of the halocline acted as a barrier for organic matter transfer from the surface to the depth.

PRIMARY PRODUCTION AND SHORT TERM CARBON EXPORT IN SOUTHERN ADRIATIC AND IONIAN SEA

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The flux of organic particles from the photic layer is the central element of the cycling of carbon and associated biogenic elements in open waters. A multidisciplinary study to assess the carbon cycle in the Southern Adriatic and Ionian basins started in the framework of the MTP 2-MATER project. The experimental activity concerned trophic conditions, primary production estimates and particle export measurement from the photic layer. The planned activity comprised also the time series collection of downward particles flux by means of sediment trap moorings. During March 97 at the Southern Adriatic station the primary production was estimated (with 24 h in situ incubation) in 340 mg C m^2 d^{-1}. The organic carbon fluxes, obtained with a drifting trap experiment, decreased with depth varying from 6.5 mg C m^{-2} d^{-1} at 25 m depth to 2 mg C m^{-2} d^{-1} at 125 m depth, suggesting enhanced carbon recycling in the upper water column. In fact the percentage of carbon export was estimated 2.8 % in the 0-25 m layer and decreased to 1 % at 50 m depth.

INFLUENCE OF SUBMARINE GROUNDWATER DISCHARGE ON COASTAL OCEANOGRAPHIC PROCESSES

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Recognition of the importance of groundwater flow into surface waters as a pathway for dissolved constituents has increased dramatically in the last few years. As one specific example, the Russian Academy of Sciences together with the "Land-Ocean Interactions in the Coastal Zone" (LOICZ) Project of the International Geosphere Biosphere Program convened an international workshop in Moscow entitled "Groundwater Discharge in the Coastal Zone." The initial impetus for convening the symposium stemmed from the recognition that an understanding of the dynamics of the coastal zone required knowledge of all inputs, and that in some locations the contribution of groundwater discharge, although not as easily recognized as oceanic exchange or surface flow, could be important. Our intention is to pick up where the LOICZ symposium left off and focus on the key problems. Submarine groundwater discharge (SGD) has been documented to be significant for nutrient input in some regions, and could be of importance for issues relating to pathways of pollutants to the ocean as well as various naval operations (acoustic interference, etc.). The direct discharge of groundwater into standing bodies of water may also have significant environmental consequences. Since the concentration of dissolved solids is typically much higher in groundwaters than surface waters, the impact of SGD on coastal chemistry and ecology may be considerably greater than one would estimate based on discharge assessments alone. In our paper we will review and identify deficiencies in our knowledge concerning the influence of SGD on coastal oceanographic processes.

THE ATMOSPHERIC FLUX OF DIMETHYL SULPHIDE FROM A SOUTHWEST EUROPEAN ESTUARY

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Seasonal dimethyl sulphide (DMS) emissions from an estuarine environment (Canal de Mira, Ria de Aveiro, Portugal) were investigated by parallel measurements in waters and tidal flats. Dissolved DMS concentrations were measured by GC/FPD following extraction from water samples using a cryogenic purge and trap technique. The fluxes were then estimated from a classical sea-air exchange model. A dynamic gas emission chamber in connection with canister sampling and GC/FPD analysis was employed for direct measurements of DMS fluxes from intertidal mud flats into the atmosphere. The field measurements showed significant longitudinal gradients for dissolved DMS in the waters. These results can be to some extent interpreted with reference to supporting hydrological parameters like salinity, temperature and chlorophyll *a*. On the other hand, the data obtained from this study revealed pronounced seasonal variations for DMS fluxes with peak values during the warmer months. The relative contribution of estuarine waters and mud flats for local DMS budget is discussed in terms of tidal cycles and exposed surface area.

in-situ studies of biogeochemical processes occuring at the deep-sea floor : first results obtained with the Banyuls Benthic Lander

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The biogeochemical cycling of organic matter at the sediment water interface of seafloor consists of a bulk of biological and physical processes catalyzing chemical reactions and facilitating material exchange. In the framework of this problematics, the Banyuls Benthic Lander has been deployed in spring and summer at several sites of the Gulf of Lions continental margin, from coastal zone to deep stations. This apparatus presents the capability to perform many tasks: (i) sampling and/or injecting in the overlying waters at pre-programed times. (ii) continuously measuring the oxygen concentration. (iii) recovering the sediment at the end of the experiment. Two C-14 radiolabelled organic compounds were injected to follow their fate during early diagenesis: an autochtonous labile molecule (glutamic acid) and in contrast a more refractory molecule originating from continental inputs (benzoic acid). The temporal variations of oxygen concentration provides good informations on the global biological activity. Benthic foraminifera were sorted and determined on the species level to characterize abundance and microhabitat patterns; meiofauna and macrofauna have been measured in term of number and biomass. The results allows to clearly distinguish the benthic activities from coastal to deepest areas, and the different bathymorphological sites of the continental slope.

X-RAY FLUORESCENCE ELEMENTAL ANALYSIS OF PM-10 AIRBORNE PARTICULATE AT A MEDITERRANEAN COASTAL SITE (CASTELLON, SPAIN)

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Atmospheric aerosol samples were collected near the coast at Castell¾n (a Mediterranean Spanish city). During a period of six months between February and August of 1992, a daily sample was collected by means a medium-vol sampler equipped with a PM-10 inlet using Millipore ester mixed membrane filters as collection media. Elemental chemical analysis of samples obtained were performed by a Siemens S-3000 X-ray fluorescence spectrometer (SEM/EDX), using SRM -1648 (urban particulate matter) as reference material for calibration. Significant amounts of Na, Mg, Al, Si, S, Cl, K, Ca, V, Cr, Mn, Fe, Zn and Pb were found. Ambient concentrations were calculated for each element. Statistical correlation between elements and time temporal series showing a seven order correlation were find. Authors are grateful to the Fundaci¾ Caixa Castell¾ for financial support throws the 61383 project.

VARIABILITY OF THE PRIMARY PRODUCTION AND F RATIO IN A MEDITERANEAN COASTAL ZONE DURING SPRING BLOOM.

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Hydrological and productivity measurements were conducted weekly from March to May 1997 (spring bloom) in the north-eastern part of Gulf of Lions (off Marseilles) during the High Frequency Flux project (MAST III-MATER) in collaboration with the Programme National d'Océanographie Côtière (PNOC). The study site was sampled by nine stations (over 700 km^2) during a set of six daily cruises (one-week intervals). Aims of this study were to demonstrate if small-scale spatial and temporal variabilities had to be taken into account in a shelf region for future studies on primary productivity in Gulf of Lions. Chemical and biological data show the influence of hydrological and meteorological events (as well as North Mediterranean Current and forcing of north-westerly winds). Two sets of spatial distributions reveal that *f*-ratio (percentage of new production) and mean primary production ranges from 15% to 51% and 300 to 500mgC m^{-2} d^{-1} respectively. Beyond these latter mean values an important variability exists and several values reach 600 or even 1000mgC m^{-2} d^{-1}. Results reveal rather low productivity for the season with a patchy distribution pattern reflecting the nutrients availability in the area. Thus variability leads to a large range of new production in term of carbon (40-400mg m^{-2} d^{-1}). Finally a linear relationship could be established between primary production and new production.

Simulation of the Cd and Mn behaviour in the Danube mixing zone using stable and radioactive trace elements as indicators.

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Artificial salinity gradient experiments were performed by mixing unfiltered water from the Danube River previously (24 hours) spiked with stable or radionuclides trace metals with filtered (0.4 µm) Black Sea water (salinity 17.8). After mixing for 24 hours, the separation between the particulate and the dissolved phase was done. This period allows us to consider an equilibrium for Cd reactions and a pseudo equilibrium for Mn. Both experiments using stable or radionuclides, simulated well the removal of Cd and Mn observed from field sampling and from an un-tagged mixing experiment. For Cd (and to a lesser extent for Mn) the removal is known to be due to the formation of chloro and sulfato complexes in solution. By coupling stable and radioactive trace elements as indicators of the particulate-dissolved interactions, the contribution of the labile and residual species was specified. According to the type of experiments, different distribution coefficients (Kd) for Cd and Mn were calculated and results are discussed with respect to the importance of the sorbed labile species.

VERTICAL FLUXES OF ORGANIC SPECIES IN A COASTAL MARINE AREA (EASTERN MEDITERRANEAN): AUTOCHTHONOUS VS. ALLOCHTHONOUS CONTRIBUTION.

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Two time-series sediment traps were moored for one year period (Nov. 1994 to Nov. 1995) in the southern Cretan sea margin (1550 m water depth), at 200 and 1500 m depth in the frame of CINCS project. Detailed investigation of 7 distinct lipid classes permitted to distinguish the various organic matter sources, both natural (planktonic/microbial autochthonous and continental inputs) and anthropogenic ones. While generally higher concentrations of the organic constituents were found at 200 m, higher fluxes were measured for the deeper deployment. Moreover, the enhanced concentration of terrestrially-derived organic markers at 1500 m in late winter, may be attributed to resuspension processes. The peak of long chain alkenones and brassicasterol (coccolithophorid markers) at 200 and 1500 m in late April, is consistent with a high carbonate input on the same time. Anthropogenic inputs were found in low concentrations and showed a mixted petrogenic/pyrolytic character during summer, while a pyrolytic character was predominant during winter time.

ANNUAL CYCLE OF PLANCTON ACTIVITY AND DMS PRODUCTION IN A COASTAL ZONE

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The aim of this research was to study the seasonal variations of the DMS production in relation to the plankton communities. The research was realized in an area (station A) of a perturbed littoral marine ecosystem (Toulon Bay, Var, France) and compared with a less polluted one (station B) located outside the bay, in order to define the factors influencing the marine production of DMS. Measurements of DMS concentration in seawater, meteorological conditions, abiotic parameters of the water quality and samplings of phyto- and zooplankton were realised almost once a month from January 1997 to December 1997. Our results showed a difference in the production of DMS between the innern bay and outside the bay (concentration average in the bay is 1.4 times higher than outside). In the same way and on the whole study, phyto- and zooplankton densities were higher inside the bay than outside. It was found that an increase in chlorophyll "a" was followed by an increase of DMS. Our data indicated also a highly positive correlation between phytoplancton biomass and DMS concentration in both station. Production of DMS was associated with specific algae taxonomic groups. Concerning zooplancton, the only significant correlation with DMS was found in station A due to grazing activities.

BIOGEOCHEMICAL PROCESSES AFFECTING THE DISTRIBUTION OF TRACE METALS IN THE DANUBE MIXING ZONE

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The distribution of trace metals (Cd, Cu, Zn, Pb, Fe, Mn and Co) were established for the three main branches of the Danube river during two campaigns (July 1995 and April-May 1997). The dissolved concentrations established for the river end-member do not indicate contamination with regard to anthropogenic metals such as Cd, Pb and Zn. The low concentrations measured, in particular for Fe, are attributed to the precipitation of hydrated oxides, as a consequence of the high pH of the river (>8). The evolution of the dissolved concentrations of trace metals along the salinity gradient from the river end-member to the open waters of the north-western Black Sea (salinity=18) show only modest transfer between the particulate and the dissolved phase. The contrasted biological activity encountered during the second campaign is considered to explain the behaviour observed for some metals (such as Cu).
In addition, salinity gradient was simulated by in-vitro experiments, performed under dark conditions by (1) mixing freshwater with filtered marine end-member and (2) mixing spiked (with stable metals) freshwater with filtered marine end-member. Results of these experiments on both the particulate and the dissolved phase allow us to clarify the adsoption/desorption mechanisms at the solid-liquid interface.

TEMPORAL PATTERNS OF CADMIUM CONTAMINATION WITHIN THE LOT-GARONNE-GIRONDE (FRANCE) FLUVIAL SYSTEM.

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Oysters in the Gironde estuary present anomalously high cadmium concentrations which have been related to the fluvial transport of cadmium derived from mining activities in the upper Lot river valley which started in the middle of last century. Since 1990, we have investigated monthly variations of dissolved and particulate cadmium concentrations and fluxes in the Lot and Garonne rivers. Total Cd export fluxes from the Lot river show high temporal changes related to the local climate and range from 2 to 20 $T.yr^{-1}$. Cadmium and radionuclides (^{210}Pb and ^{137}Cs) data from 7 sediment cores collected between the pollution source area and the Gironde estuary have allowed to assess the spatial and temporal impact of a pollution peak event which occurred in 1986. From our study we can conclude that even if the Lot pollution source decreases drastically in the near future, the cadmium contamination of the estuary will remain for decades. Indeed, since a major stock of pollution derived cadmium is present in the Lot river sediments (about 130 T in 1996), the Gironde estuary will still exhibit high dissolved cadmium concentrations derived from the desorption of cadmium from suspended particles in saline estuarine waters.

SIMULATIONS OF CFC12 DISTRIBUTIONS WITH A GCM OF THE MEDITERRANEAN SEA

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A Mediterranean general circulation model is used to study the formation and pathways of deep water in the eastern and western basins. The CFC12 distributions measured in both basins by the German ship, Meteor (Roether etal 1991, Kline etal 1997) are simulated in the model and used to assess the GCM's representation of transport. Early versions of the model were unable to reproduce the overflow of water at the straits connecting Mediterranean sub-basins. This problem was overcome by incorporating the Gent and McWilliams parametrization scheme. In order for the model to carry tracers effectively it was necessary to incorporate a flux limiting advection scheme, Thuburn (1993), Stratford (1997) into both the resolved, and Gent and McWilliams advection terms, to prevent negative concentrations occuring. Simulations at different resolution are shown.

SOURCES OF SULPHATES AND ORGANIC COMPOUNDS IN SUBMICRON MARINE AEROSOL

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Main sources, size distributions of organic components (including MSA, its salts) and nonseasalt SO_4 ($n_{ss}SO_4$), are discussed on the basis of fractional analysis of IR absorption spectra of aerosol samples collected over different regions of the Pacific and Atlantic oceans. Basic attention is given to the analysis of samples collected over remote regions with high biological productivity where the oxydants of DMS, COS etc emited from sea water define considerably the chemical composition of submicron aerosols over oceans. Maximal presence of the organics is observed in aerosols collected over remote oceanic areas with high concentration of primary organics and phytoplankton whose activity is directly linked with vertical streams exerting intense water mixing. The fractional analysis of the IR spectra evidences in favour of heterogeneous condensation of DMS oxydants onto sea–salt particles. The presense of bands of other organic compounds (intense bands of CH_2, CH_3 groups etc) pushes to the assumption on possible contribution to the particulate organics from two other sinks: i. organic hydrosol–aerosol transition, and ii. particles originated from slicks highly enriched with surface active hydrophobic organics like fatty acids, higher alcohols etc. As a rule, in the particles collected over remote regions of the Pacific ocean low concentrations of $(NH_4)_2SO_4$ are observed in contrast to highly polluted areas of the Atlantic ocean where the main component of the $n_{ss}SO_4$ is $(NH_4)_2SO_4$.

ISOTOPIC AND ELEMENTAL VARIABILITY OF CU AND ZN IN SEDIMENT TRAP MATERIAL FROM THE CENTRAL ATLANTIC OCEAN

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Sediment trap material was collected in the Central Atlantic Ocean, west of the Mauritanian coast, under mesotrophic conditions. During the blooms of 1991, Cu concentrations increase between 1000 and 2500 m and Zn concentrations decrease by about 50%. Such a behavior documents both Cu scavenging and Zn remineralization during particles transit in the water column. The residence times corresponding to these processes are estimated to be respectively about 200 yrs and 60 yrs. A breakdown of the Cu and Zn crop of the 250 m trap into components shows that the signal is quantitatively associated with the major particulate fractions (organic matter mostly planktonic, carbonates, and aluminum silicates). Such a breakdown cannot be carried out at deeper levels, probably because of scavenging and remineralization. The isotopic composition of Cu and Zn in particulate material was measured for the first time by plasma source mass spectrometry on the P54 of Lyon which is equipped with both multiple collection and magnetic sector. The $^{65}Cu/^{63}Cu$ and $^{66}Zn/^{64}Zn$ ratios are measured alternately on the samples and on a standard solution of the same element. The internal reproducibility of the isotopic measurements is 0.04‰. Sediment trap material shows regular and coherent isotopic variations of 0.4‰ for $\delta^{65}Cu$ and 0.2‰ for $\delta^{66}Zn$. We suggest that the isotopic variability is controlled by the preferential uptake of the light isotope by biological activity. The isotopic patterns reflect changes in either the local productivity or in the vertical advection of water masses with different preformed isotopic values.

PHOSPHATES IN RAINWATERS : TOTAL FLUXES AND PARTITIONING BETWEEN LABILE AND REFRACTORY PHASES

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Phosphate concentrations in rainwaters are measured on a Ligurian coastal sampling site (Cap Ferrat, France) since february 1997. Labile and refractory phosphates are discriminated in order to evaluate the atmospheric supply of available P. Preliminary results show a high temporal variability in total concentrations (from 0.05 to 4.3 $\mu mol.l^{-1}$). The amounts of P strongly depend on the emission sources. With the help of chemical criteria and air-mass trajectory analyses, soil-derived dust from Sahara is identificated as the major source of atmospheric P. To a lesser extent, anthropogenic emissions may exhibit high P concentrations. Wet P fluxes are also calculated. Although the partitioning between labile and refractory P is very variable, Saharan inputs generally exhibit a higher percentage of labile P. The labile P content presumably determines the impact of atmospheric P inputs on surface seawater, which may be significant when P inputs from deeper waters into the the photic layer are minimum. Their possible role in fertilization in oligotrophic zones (or periods) is tackled.

GEOCHEMICAL IMPLICATIONS OF ATMOSPHERIC LEAD DECREASE ON THE MEDITERRANEAN SEA ENVIRONMENT.

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As a consequence of the European regulations on leaded additive gasolines, the annual Pb automotive consumption decreased from 10,000 to 1500 tonnes between 1987 and 1996 in France. The marine biogeochemical impact of the Pb emission evolutions during this period is evaluated from data concerning: atmospheric Pb deposition fluxes since 1986, annual profiles of marine concentrations between 1983 and 1996, and oceanic fluxes measured in the Ligurian Sea during six months, at 200 and 1000 m in spring 1987 and 1993. The temporal evolution of Pb standing crop in surface, intermediate and deep waters between 1983 and 1996 reflects the variations of Pb emissions. This tendency is evidenced by the comparison of Pb fluxes: a similar decrease (90%) is observed for atmospheric and oceanic fluxes between 1983 and 1993, meanwhile a decrease of 45% occurs for Pb standing crop in surface and intermediate waters. At the present time, it can be assumed that biological activity is sufficient to transfer the atmospheric Pb loadings. These results seem consistent with the observed evolution of Pb profile concentrations in the Ligurian Sea between 1983 and 1996.

MODELLING BIOGEOCHEMICAL CYCLES IN A COASTAL ZONE: SENSITIVITY TO NUTRIENT INPUTS FROM RIVERS AND SEDIMENTS

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The coastal zone is known as a very active biogeochemical reactor, transforming and producing large amounts of matter that remain difficult to estimate with in situ data. Therefore, in order to quantify the main biogeochemical cycles (C, N, Si) in an open margin zone (the Gulf of Lions), we developed a biogeochemical conceptual and numerical model which has been implemented in a three-dimensional model of hydrodynamics. The simulation of the annual cycle allows us to describe the spatio-temporal evolution of the ecosystem and to stress the importance of lateral transport and vertical mixing on the development of phytoplankton. Integrated fluxes of nitrate through the shallow area of the domain amounted to 70 000 tons of N-NO3 per year, i.e. about 5 % of the annual advective flux, or 120 % of the annual flux of nitrate brought up by vertical mixing. The importance of this export flux is directly linked to nutrient inputs from the Rhone river, from the sediments, and from advection of the Northern Current. Therefore, we have used this coupled model to determine the sensitivity of primary production and regeneration processes to these inputs. Results demonstrate the non-linear effects of input processes on total primary production in the coastal zone.

ARE NATURAL RADIONUCLIDES SUITABLE CARBON CYCLE TRACERS IN THE MEDITERRANEAN?

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The distributions of the particle reactive, short-lived radionuclides ^{234}Th and ^{210}Po, between the particulate and dissolved phases, relative to their parent species, have been used successfully in radionuclide scavenging models to elucidate carbon export rates from the euphotic zone in the open ocean, where particles are dominantly biogenic. This paper asks whether these models can be applied to coastal and shelf seas which are globally important areas of production and where a more complex situation exists in which lithogenic and authigenic particles also act as scavenging agents. ^{234}Th distributions in the southern Adriatic and northern Ionian Seas are only partly related to biological parameters such as POC, and to a greater extent reflect the distribution of iron oxy-hydroxides, the dominant source of which is the River Po. Marked disequilibrium between ^{234}Th and its parent ^{238}U cannot be accounted for by the abundance of particles in the water column at the sampling locations. Instead, it is proposed that this disequilibrium is the result of intense scavenging processes associated with the Po outflow in the northern Adriatic, thus rendering standard radionuclide scavenging models invalid. The possibility is examined of combining scavenging data from ^{234}Th and ^{210}Po, which have been shown to react differently to biogenic particles in laboratory studies, to evaluate carbon export.

TOTAL ATMOSPHERIC FLUXES OF TRACE METALS IN NORTHWESTERN MEDITERRANEAN FROM 2 YEARS MEASUREMENT (1995 to 1997)

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Total atmospheric deposition of metals was monitored during 2 years (1-95 to 3-97). The sampling site, located on the Northwestern coast of Corsica, was chosen for being isolated from any local contamination sources and represents a quite good observatory for the air quality in the Northwestern Mediterranean. The total atmospheric fluxes were established for: Al, Fe, Mn, Ni, Cu, Pb, Cd and Zn. Al, used as the crustal reference, indicates that Pb, Cd et Zn are associated mainly to anthropogenic aerosols (80-100%) and Fe to crustal aerosols (97%). In order to determine the spatio-temporal variability of the trace metals over the Northwestern Mediterranean, the observed mean fluxes are compared with those previously published. They are systematically lower, except for Ni and Mn. Concerning Cd and Zn, this difference could be attributed to (1) the fact that the sampling site is better isolated from local and regional contaminations than the other sites or/and (2) a decrease of the aerosol concentrations over the whole area in 10 years. The mean flux of Pb (1±1 $kg.km^{-2}.an^{-1}$) confirms the decrease of atmospheric Pb over the northwestern Mediterranean induced by the recent limitation in the use of Pb additives in gasoline. In the case of Al and Fe, the observed decrease corresponds to a decrease of the Saharan dust deposition.

TRACE METAL DISSOLVED AND PARTICULATE PHASES IN ATMOSPHERIC INPUTS

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The physico-chemical state in which atmospherically-transported metals settle on the sea surface is of major importance regarding their fate in the water column and, if any, for a possible environmental harm. The incorporation of trace elements in biological cycles may also depends on their phase. Rainwaters and total deposition are collected at a permanent coastal sampling station at Cap Ferrat (French Ligurian coast). Total deposition being the sum of dry and wet depositions, the dry fluxes are calculated. From these data, total fluxes are evaluated for Al, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Ni, Na, Pb, Sr, Ti and Zn, with discriminating dissolved (in rainwaters) and particulate (in rainwaters and dry deposition) fractions. The respective ratios dissolved/particulate are considered taking into account the emission sources of trace metals : elements of crustal origin exhibit a low dissolved (presumably bioavailable) fraction, while those emitted by anthropogenic activities are essentially deposited under dissolved form. At a global scale, these different fates in the water column should determine very different biogeochemical behaviours.

MESOSCALE ESTIMATION OF PARTICLE DYNAMIC, DERIVED FROM ^{234}Th, IN SURFACE WATERS ACROSS THE IBERIAN MARGIN

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The Iberian Margin, which is characterised by a narrow shelf and steep slopes, is strongly influenced by seasonal and spatially localised upwelling, downwelling, river inputs and slope currents. Such sporadic and local input of nutrients is likely to produce considerable spatial variability of biological activity, and consequently of particle flux. In surface waters, particulate fluxes can be estimated from ^{234}Th which is activity. Indeed ^{234}Th ($t_{1/2}$ = 24.1 d.) is the most suitable radiotracer with its short period for studying particle export on timescales of days to weeks.
During OMEX II (MAST programme) cruise (June, 97), samples for dissolved and particulate ^{234}Th determination were collected. In order to estimate the mesoscale variability of fluxes, 23 stations were sampled in an area covering 41 to 43°N and 9° to 10°E. Except at 3 stations where detailed profiles were established, ^{234}Th activity was sampled between surface and 50 m as a single vertically integrated sample for each station.
Spatial distribution of particle fluxes and residence time, derived from ^{234}Th activities, will be discuss in relation with hydrological features.

CHEMICAL CHARACTERIZATION OF INDIVIDUAL AEROSOL PARTICLES COLLECTED BY CASCADE IMPACTOR SAMPLING AT CASTELLON (SPAIN)

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Atmospheric aerosol samples were collected near the coast at Castell¾n (a Mediterranean Spanish city), during a period of seven months between April and December of 1992 using a high-volume sampler equipped with a five stages cascade impactor without filters. Individual particle analysis of samples obtained was performed by a Scanning Electron Microscope equipped with an energy dispersive X-ray spectrometer (SEM/EDX), on hexane dispersed particulate using the McCrone Atlas for identification. Following elements were found: Na, Mg, Al, Si, S, Cl, K. Ca and Fe. Several groups of particles according their chemical composition were created and its natural or anthropogenic origin determined. Authors are grateful to the Fundaci¾ Caixa Castell¾ for financial support throws the 61383 project.

Interannual variability of fluxes across the North Sea boundaries

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Interannual variability of the fluxes across the North Sea boundaries and the fluxes between North Sea and Baltic Sea were studied with a 3-d numerical model for the North Sea and the Baltic Sea. The model is a coupled ice/ocean model and is applied to the integrated system of the two marginal seas. A prognostic model run for the period 1982-1988 was carried out and analysed. Strong interannual variability of the fluxes across the boundaries were found and extreme events were discussed. The implications of this variability on nutrient transports were discussed and budget calculations for the different years were presented.

CONTROL OF pH BY ROCK-WATER INTERACTIONS WITH IMPLICATIONS TO AIR-SEA EXCHANGE OF CARBON DIOXIDE IN A TROPICAL ESTUARINE (MANDOVI-ZUARI) COMPLEX

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The concentrations of river or seawater borne substances may be modified by biogeochemical processes occurring in estuaries. pH changes regulate carbonate equilibria in water and vice versa. Although, the pH of river waters is governed by the nature of rocks in the catchment area and industrial and aquaculture effluents can also influence significantly. The pH exhibited somewhat similar curve to that expected from linear mixing between river and seawaters suggesting that the pH largely behaves conservatively. But our laboratory experiments revealed that pH behaves non-conservatively. Our experiments with soils revealed that the lowering of pH in the estuarine system is mainly because of the rock-water interaction in estuarine water. pCO_2 varied from ~80 to 720 µatm and air-sea fluxes of carbon dioxide ranged from -30.2 to 55 $mM.m^{-2}.d^{-1}$. Sofar, coastal, estuarine and riverine regions are considered a sink for anthropogenic carbon dioxide. This study reveals that these regions also act as a source to the atmospheric carbon dioxide depending on the nature of the rocks /sediments. Hence, we need to re-examine these regions.

AN APPROACH TO MODELLING ANOXIC CONDITIONS FORMATION AS AN EXAMPLE OF THE BLACK SEA REDOX LAYER

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The study of anoxic conditions is important because they can be formed in both natural and anthropogenic ways. A representative case study of the oxic anoxic transformation is the Black Sea redox layer. In anoxic conditions the oxidation of organic matter occurs in different stoichimetric reactions. Hence modelling of oxic/anoxic transformation requires parameterization of the cycles of several elements simultaneously, in contrast to models dealing only with nutrient cycles under oxic conditions. An O-N-S-Mn model is considered. Rates of biochemical processes are described using semiempirical functions of oxygen concentration. The processes of turbulent diffusion, sedimentation, and biogeochemical transformation were paramaterized in the frames of 1D and 2D coupled models. The calculated spatial distributions of nitrogen compounds (organic nitrogen, ammonium, nitrate, nitrite), sulfur compounds (sulfide, elemental sulfur, thiosulfate, sulfate), dissolved and particulate manganese as well as dissolved oxygen agree reasonably well with the observations. Model estimations confirm that the existence of anoxic conditions is controlled by the peculiarities of organic matter decay (a consequence of oxidant consumption) in conjunction with restricted aeration. The results obtained could be used to describe the nitrogen, sulphur and manganese cycles in other natural aquatic ecosystems where anoxic environments are present or possible.

SIMULATION OF THE SEASONAL CYCLE OF THE ADRIATIC SEA ECOSYSTEM WITH AN HIGH RESOLUTION COUPLED ECOSYSTEM MODEL

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An high resolution simulation of the Adriatic Sea ecosystem spatial and temporal variability, under climatological forcing conditions, has been carried out utilizing the coupled ERSEM-POM (European Regional Seas Ecosystem Model - Princeton Ocean Model) system.
The physical component of the model (POM) is forced with perpetual year seasonal cycle of the atmospheric forcing and river runoff, while climatological solar radiation and riverborne nutrients inputs are forcing the biogeochemical processes described by ERSEM.
Results relative to the simulation of the seasonal cycle of the primary production processes are shown along with the spatial variability of the phytoplankton biomass and nutrients concentration, resulting mainly in a north to south trophic gradient. Emphasis is also put on the detailed description of the spatial variability of the circulation features (allowed by the high model resolution) which are greatly affecting the variability of the biogeochemical processes.

NP3 Transport and mixing in geophysical flows

Convener: Legras, B.

04 Biological processes and mixing in the ocean (joint with OA)

Convener: Richards, K.J.

Interplay of Fluid Dynamics & Plankton Population Dynamics in the Ocean

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Plankton is a collective term describing many species of small (usually 10^{-4} - 10^{-2}m) plantlike, photosynthesising (phytoplankton, P) or animal like, herbivore (zooplankton, Z) organisms. Growth needs a nutrient supply (N), together with available radiation. Striking features of the population dynamics are its spatial and temporal variability. Blooms, in which the population of P (and to a lesser extent Z) increases by 1-2 orders of magnitude in a few days, occur at some times and places, often unpredictably, and spatial patchiness is ubiquitous. Mathematical models range from highly complex, amenable only to numerical simulations, to very simple, allowing the possibility of some analytical understanding and hence predictive properties. Here we report results from simple (NPZ) population models, comprising coupled differential equations of excitable nature. Effects of non-uniform flow fields on the dynamics of these models are explored, both when the plankton is entirely passive, and also when the zooplankton adopts feeding strategies involving relative motion. Implications for blooms and spatial patchiness are discussed.

RELATIONS BETWEEN PHYTOPLANKTON AND TRACE METALS

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Laboratory experiments were conducted in order to describe the main interactions between phytoplankton and trace metals in the column water of the Gulf of Lions. Two marine microalgae present in this environment, the prymnesiophyte *Emiliania huxleyi* and the diatom *Leptocylindrus danicus*, were grown in two axenic seawater medium : (1) the F/2 medium and (2) a seawater-like trace metals concentrations. The aim of these experiments is to investigate the trace metals (Cd, Cu, Fe and Zn) distribution between the dissolved and the particulate phases for these two species at the different steps of the algae growth, in the two medium. On the contrary of *Emiliania huxleyi*, the growth rate of *Leptocylindrus danicus* is maximum in the medium enriched in trace metals (F/2). Lower trace metals concentrations of the second medium induce a decrease with a factor 2 and 3 of the Chl *a* levels for *Leptocylindrus danicus* and *Emiliania huxleyi*, respectively. These experiments will allow us to determine the distribution coefficient Kd, the relation between the phytoplankton and particulate trace metals. Results will be included into the 1D water column model (Tusseau et al., 1997) currently modified to describe the fate of these trace metals in the column water in relation with the organic matter. (This work is part of the E.U Metro-Med Project (MAST3-CT96-0049)).

EFFECTS OF ADVECTION, MIXING AND SINKING ON SPATIAL AND TEMPORAL EVOLUTION OF BIOCHEMICAL PARAMETERS IN THE MEDITERRANEAN SEA

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In the Mediterranean Sea, average fluxes of matter have opposite directions in the upper ocean, one being eastward oriented and the intermediate one, controlled by LIW, westward. As a consequence fluxes caused by advection, mixing and sinking velocity of particulate matter, strongly affect horizontal spatial distribution and play a major role in giving rise trophic gradient. In this communication, we investigate the effect of sinking velocity on spatial and temporal evolution of biological parameters. Also the influences of advection and mixing are analyzed. Numerical results are obtained with a three-dimensional hydrodynamical ecological model, using a lumped variable description of the first trophic level, while the transport processes are accounted for by a MOM-like structure. They indicate that the sinking term originates a west-east gradient on biological parameters, while large gyres determine the prevailing trophic regime in the open ocean and upwellings/downwellings are most effective along the coastal areas.

A MODEL STUDY OF THE EFFECT OF VERTICAL MIXING ON THE MARINE ECOSYSTEM

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A coupled 3-dimensional physical-biogeochemical ocean model is used to quantify the effect of vertical mixing on the marine ecosystem in the Atlantic Ocean, the Nordic Seas, and the Arctic Ocean. The physical model used in this study is the Miami Isopycnic Coordinate Ocean Model MICOM, with a dynamic-thermodynamic ice model, whereas differet nitrogen-based ecosystem formulations are used. Three mixing processes are examined: Mixed layer entrainment/detrainment, convective mixing, and diapycnal mixing. For the latter process, different parameterizations are tested, including vertical stability and isopycnic velocity shear dependent formulations. The presentation will focus on the effect these mixing processes have on new, regenerated and export productions in the open ocean, together with the air-sea exchange of CO_2.

COUPLED HYDRODYNAMIC ECOSYSTEM MODEL OF THE BLACK SEA AT BASIN SCALE. FIRST RESULTS OF A HIGH RESOLUTION 3D INTERDISCIPLINARY MODEL

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A hydrodynamical model of the general circulation in the Black sea has been build up, using the GHER (GeoHydrodynamics and Environment Research) three-dimensional, non linear, baroclinic, turbulent closure model. A model with 5 km horizontal resolution and 25 vertical levels is used to compute the typical seasonal cycle by forcing the model with climatological monthly mean fields of temperature, salinity and wind stress at the air-sea interface. Furthermore, the river discharges of the Danube, the Dnestr and the Dnepr are taken into account. This high resolution model resolves the baroclinic instabilities generated by the interactions of the boundary current with the coastline geometry or with the continental shelf/slope topography.
A simple ecosystem model defined by a nitrogen cycle is coupled with the hydrodynamical model. The state variables of this model are defined as those which are necessary and sufficient to assess the effects of the physical processes, and in particular of the boundary current instability, on the space time distribution of the primary and secondary productions.
The results of this 3D ecohydrodynamic model are compared with CZCS data of surface chlorophyll fields collected during the period from 1978 to 1986.

THE PHYTO- AND ZOOPLANKTON FIELDS OF THE ATLANTIC OCEAN.

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Data from 20 years (1970-1990) of expeditions to the Atlantic Ocean are summarised in the form of macroscale contour maps. The chlorophyll *a* concentrations from surface and mesozooplankton in the upper layer (0-100m) were analysed from 3000 and 1300 casts respectively. General agreement between chlorophyll concentrations and mesozooplankton biomass distributions was noted on an ocean basin scale. The comparison of chlorophyll concentration within the surface layer for some cruises and CZCS data was made for individual provinces. For the open ocean there was significant correlation between *in situ* measured and satellite derived chlorophyll concentration. There was a linear relationship between mean chlorophyll concentration within the 0 to 10 m layer and mesozooplankton biomass within the 0 to 100 m layer for 9 biogeochemical provinces for summed data between December to May and June to November. For certain provinces relations were established between primary production, phytoplankton and zooplankton biomass. Biomass of phytoplankton and zooplankton were estimated for the biogeochemical provinces of Atlantic Ocean. The total biomass of phytoplankton was estimated at 100 mln t C, and that of mesozooplankton at 65 mln t C.

THE EFFECT OF HYDRODYNAMICS ON THE PHYTOPLANKTON PRIMARY PRODUCTION AND SPECIES COMPOSITION AT THE ENTRANCE TO THE GULF OF FINLAND (BALTIC SEA) IN JULY 1996.

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A two-week multidisciplinary experiment at the entrance to the Gulf of Finland with the aim to study the development of the late summer phytoplankton bloom and the controlling hydrodynamic mechanisms was carried out in July 1996. During the study period a clearly defined physical phenomenon - an anticyclonic eddy - was observed. The formation of the anticyclonic eddy was clearly reflected in the horizontal patterns of patchiness of phytoplankton. Diazotrophic cyanobacteria are favoured by low DIN and DIP concentrations because of overcompetition with other planktonic organisms. Proportion of cyanobacteria in the plankton community was the highest outside the observed eddy. The presumed vertical fluxes in the anticyclonic eddy appeared to be sufficient to control phytoplankton dynamics: the flagellates are favoured in case of continuous vertical transport of nutrients and, therefore, the flagellates abundance was higher in the centre and periphery of the eddy. Wind-induced vertical mixing was instrumental in bringing nutrient pulses to the upper mixed layer outside of the eddy and due to these pulses, temporal increases of phytoplankton (especially cyanobacterial) production was confirmed. A good correlation between preceding day wind speed and the phytoplankton primary production outside of the observed eddy was found.

THE IMPACT OF MESOSCALE EDDIES ON PRIMARY PRODUCTION IN THE NORTH ATLANTIC OCEAN: A MODELLING APPROACH

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Physical influences on biological primary production in the North Atlantic ocean are examined by coupling a four-component ecosystem model of nitrogen cycling to an eddy-resolving seasonal general circulation model. A series of sensitivity experiments shows the crucial role of an accurate formulation of upper ocean turbulence and of advection numerics. Subgridscale diapycnal diffusion strongly controls biological production in the subtropical gyre, while an accurate description of subgridscale viscosity is important in the equatorial region.
Assimilation of altimeter data from the combined TOPEX/Poseidon and ERS-1 missions into this basin-wide high-resolution model is performed to yield a more realistic representation of oceanic eddy activity. Results indicate that mesoscale activity accounts for more than one third of the new primary production in large regions of the subtropical and mid-latitude North Atlantic. Variational assimilation of ocean colour data in this coupled model is then conducted to constrain the modelled biological processes, and in particular to improve our estimation of poorly known biological parameters at a basin scale.

PROJECTED DISPLACEMENT STATISTICS IN THE OCEAN

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Results from numerical models of unforced barotropic geostrophic turbulence over topography suggest that horizontal mixing is preferentially oriented along contours of the mean PV, here $f/H(x,y)$. This is most obvious if one considers displacement statistics in a coordinate system defined by the isolines of f/H. Here, I discuss what happens when one calculates such displacements for actual oceanic floats, and, in addition, regional and vertical variations of the corresponding statistics. The results indicate that oceanic mixing is also anisotropic with respect to f/H, implying in turn that topography affects the spread of tracer in large regions of the ocean. Certain statistical aspects are suggestive of Eulerian flows observed previously in turbulence models. Furthermore, the results lead naturally to simple parameterizations of horizontal mixing in the deep ocean.

THE INFLUENCE OF PHYTOPLANKTON ON THE MIXED LAYER AND SURFACE HEAT FLUXES

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The amount of light that is absorbed in the ocean is highly dependent on the amount of phytoplankton present. In an ocean mixed-layer model the thickness of the mixed-layer is sensitive to the amount of light that penetrates into the ocean. Thus accurate modelling of the light absorption must be included in ocean mixed-layer models. As a result, the mixed-layer thickness and surface heat flux dependency on the phytoplankton concentration can be evaluated.

The calculations carried out here to model the surface heat flux and the parameters that describe the mixed-layer, are based on Niiler's 1-D model, with modifications to take into account the concentration of phytoplankton.The absorption of incoming solar radiation is modelled accurately taking into account the exact absorption properties of chlorophyll as well as a dynamically varying concentration. The mixed-layer and the surface heat flux are evaluated using a set of realistic boundary conditions with varying windstress and incoming solar radiation.

EDDY MIXING AND BIOLOGICAL PRODUCTION

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Ecological models of the upper ocean are often fitted to data by running a one dimensional version of the model and tuning adjustable parameters. However observations show that the physical, biological and chemical fields are very variable in the horizontal. The variability at the O(10km) scale is caused by the action of mesoscale eddies. Eddies mix water masses and produce vertical movement, both of which affect biological production. The affects of eddies on production need to be quantified in order that more robust ecological models can be formulated.

The effect of eddy action on production will be discussed. In particular results will be presented from a modelling study of eddy action on production. An ecological model is embedded into a physical model of an unstable oceanic front. Production is increased by the ensuing eddying motion. There is also a downward flux of material increasing the effectiveness of the biological pump. It is found that new production can be directly related to the vertical movement of nutrients into the euphotic zone caused by eddy action. A parametrization scheme based on the eddy transport scheme of Gent and McWilliams is developed and tested. the results are very encouraging and suggest a way of including the effect of eddies on biological production in basin scale ocean models.

MODELLING ANNUAL PLANKTON DYNAMIC IN THE IONIAN SEA (EASTERN MEDITERRANEAN)

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The annual cycle of the plankton dynamics in oligotrophic Mediterranean pelagic ecosystem, referring to the Ionian sea, is studied by a one-dimensional vertically resolved physical-biochemical upper ocean model, coupled with the Mellor-Yamada level 2.5 turbulence closure scheme. The biochemical model involves interaction between the inorganic nitrogen (ammonium and nitrates), single phytoplankton and zooplankton groups and detritus. As first step, under climatological forcing functions (windstress, heat and salt fluxes, photosynthetic active radiance), the model simulates main observed seasonal and vertical characteristic features as cold winter convection and yearly evolution of the upper layer stratification, the annual cycle of phytoplankton production with the weak spring bloom and the subsurface phytoplankton maximum layer stable in the summer - early autumn period.

NEW PRODUCTION IN THE EQUATORIAL PACIFIC: A COUPLED DYNAMICAL/ BIOGEOCHEMICAL MODELLING

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A simple 3D biogeochemical model was coupled to a dynamical model in order to simulate new production in the equatorial Pacific during 1992-1995. The biogeochemistry was modelled as a chlorophyll-modulated nitrate sink. The model was able to reproduce the contrasting regimes of the equatorial Pacific: the biologycally poor warm pool region and the upwelled richer waters further east. A sharp salinity front separates theses two regimes. The zonal displacements of the front are associated with ENSO wind driven surface current variations. The simulation shows that nitrate front separates the two regimes and this front moves in phase with the salinity front. The model also shows that nitrate front displacements are governed by oceanic circulation.
However, the nitrate concentrations are higher in subsurface waters than has been observed in the equatorial upwelling region. Recent results of EqPac-JGOFS strongly suggest that a significant part of the dissolved organic matter escapes remineralization and is exported. Our biogeochemical model is thus improved by adding an explicit dissolved organic nitrogen compartement.

PATHWAYS OF NUTRIENT SUPPLY TO THE OLIGOTROPHIC SUBTROPICAL GYRE: A MODEL STUDY

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Episodic nutrient pulses by eddy-induced upwelling have been suggested to explain why geochemical estimates of nitrate supply to the euphotic zone are an order of magnitude higher than biological and physical ones. The present study investigates the nutrient fluxes into the light-lit surface layer of the oligotrophic subtropical gyre with the aid of an eddy-resolving coupled biological-physical model of the North Atlantic. The level of eddy activity in the model is varied by assimilating altimeter data and by changing the parametrization of horizontal friction. The role of eddies in fueling biological production is compared with that of mean advection and different representations of subgrid-scale diapycnal mixing. It is found that eddies contribute about one third of the nutrient input into the subtropical Atlantic, but that they can not explain the large observational discrepancies. However, even within the subtropical gyre we find substantial regional differences in net nitrate supply, large enough to consistently explain the different observations. The model results are discussed with special emphasis on North Atlantic time series and process study sites.

MODELLING OF DEPOSITION/RESUSPENSION PROCESSES IN THE ENGLISH CHANNEL

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ABSTRACT
Deposition and resuspension of particulate matter offshore Roscoff (western English Channel), were studied by *in situ* measurements of sedimentation rate and physical modelling of deposition/resuspension processes. Bottom-moored and free-floating multiple sample programmable sediment traps were deployed to measure the total downward sediment flux. Particulate matter sedimentation showed short-term variations which were partly related to tidal flow speed. Particle size distributions measured over the entire deployments were quite similar at mid-depth and close to the bottom. It mainly reflected the abundance of small particles in the sedimented material. The transfer processes in the water column along with the deposition and resuspension of particulate matter were modelled. Sediment production and resuspension were evaluate from the fluxes measured in sediment traps. The results obtained are very sensitive to the physical parameter values (vertical diffusion and particle fall velocity).

NP3 Transport and mixing in geophysical flows

Convener: Legras, B.

05 Transport and mixing of chemical species in the atmosphere, including urban and regional problems in the troposphere and global-scale problems in the troposphere and stratosphere (co-sponsored by ST, joint with OA)

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MULTIVARIATE MODEL ESTIMATION USING METEOROLOGICAL PARAMETERS FOR URBAN POLLUTANTS AT GRAN CANARIA (CANARY ISLANDS).

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ARIMA model have been determined for several hourly series of pollutants at Las Palmas de Gran Canaria. Dry temperature, relative humidity and pressure have been chosen as meteorological parameters for the input of the mentioned multivariate model. It has been determined that high values of dry air temperature increase the photochemical transformations between the different pollutants. Also, the dependence of the pollutant transformation and the trade winds have been identified. Finally, stable, high-pressure episodes have been related to the pollutant persistence at the urban atmosphere.

ARIMA MODEL ESTIMATION FOR URBAN OZONE AT THE CANARY ISLANDS AND ITS RELATIONSHIP WITH OTHER POLLUTANTS

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Based on the Ozone hourly data and other different pollutants as SO2, SPM, Nitrogen Oxides and CO obtained at an urban station placed close to a power plant of Las Palmas de Gran Canaria (Canary Islands), an ARIMA model has been determined to describe its evolution. First, trend and spectral analyses using the Fast Fourier Transform (FFT) to detect the different periodicities have been carried out. Once the model has been identified, the different relationship between the Ozone and the other mentioned pollutants have been determined. In order to detect these relations, the Cross-Correlation Functions (CCF) between the different prewithened series have been used. This technique has allowed to determine the characteristic time dependence on each one, caused by the photochemical transformations between the pollutants, showing different lags between them.

THERMAL INVERSION IMPACTS ON THE MIXING PROPERTIES OF THE LOW ATMOSPHERE WITHIN A DEEP VALLEY

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Pollution problems within deep valley systems are associated to low wind conditions with significant stratification including a strong inversion layer, which reduces the exchanges towards larger scales.
Previous studies have shown that the structure as well as the characteristic scales (height, strength, and duration) of the thermal inversion within the valley strongly depend on the season. These results can be interpreted for urban pollution planning since the dynamics scales are in the same order of the reactive chemical processes.
Our contribution deals with the large eddy simulations of a complete diurnal cycle of atmospheric flows within different schematic valleys. atmosphere.
The main objectives are to point out the influence of the valley aspect ratio and the influence of the shape (convex or concave V or U-shaped valley) on the characteristic scales of the thermal inversion. The impact on the mixing properties of the lowest layers of the atmosphere, linked to the time evolution of the stratification whitin the valley, is shown through the visualization of the iso-concentration of a passive scalar emitted in the centre of the valley during three different periods : at the end of the night (when the thermal inversion is the strongest and when its vertical extension is maximum), at noon (when the inversion is the weakest or completly destroyed), and at sunset.

RELATIONSHIP BETWEEN TROPHOSPHERIC OZONE AND METEOROLOGICAL PARAMETERS AT TALIARTE (GRAN CANARIA).

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As it has been pointed out in precedent studies, ozone diurnal variations at Taliarte (Canary Islands) are dominated by two different situations: trade winds and marine breeze. Besides, a well-determined relationship between the presence of trade winds and low values of ozone registered at Taliarte, has been found. Multivariate ARIMA model and Cross Correlation Functions (CCF) have been determined to identify the influence of some meteorological parameters in the measured amount of ozone during several situations without the presence of trade winds.

A TRACER CLIMATE MODEL BASED ON THE LMDZ AGCM

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On the basis of the new LMDz atmospheric general circulation model a tracer climate model has been developped. The implicit scheme of the boundary layer and the convective and advective schemes of the GCM were altered to include passive tracer transportation. Furthermore the possibilities of dry and wet deposition as well as radioactive decay were implemented. The general features of this model have been validated simulating the atmospheric cycles of ^{222}Rn and ^{210}Pb, and lately through the simulation of mineral dust, a tracer of more climatic significance. A special feature of the applied GCM is the ability of applying a stretched grid. This means that the resolution can be increased to near mesoscale over specific areas of interest, with the model remaining global at reasonable computational cost.

TWO YEARS LIDAR AEROSOL MEASUREMENTS AT THESSALONIKI, GREECE

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Measurements of the vertical lower tropospheric profile of the aerosol backscattering coefficient have been performed at the city of Thessaloniki, since 1996 using a ground-based backscattering lidar system operating, simultaneously, at 355 nm and 532 nm. Measurements have been carried out throughout the year around local noon hours and during extensive time periods. The different aerosol loads and their vertical extension in the urban lower troposphere, between the "warm" and "cold" periods over Thessaloniki are discussed. Case studies of the diurnal evolution of the aerosol layer over the city of Thessaloniki have been examined under different meteorological conditions prevailing in the area. From the analysis of these studies the origin of the aerosol layer is indicated and the evolution of the boundary layer over the site is described. Two cases are also presented, when dust lifted from Sahara desert was transported over the measuring site. The height of this layer was determined between 3-4 km and the optical depth at 532 nm of the Sahara dust layer was found to be of the order of 0.1.

MODEL HIERARCHY FOR THE DETERMINATION OF METEOROLOGICAL AND CHEMICAL PROCESSES

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The global, regional and local scale model hierarchy ECHAM-REMO-GESIMA is being developed to improve the understanding of formation processes of photooxidants together with the changing oxidizing capacity of the atmosphere especially in the European/German area. The models are coupled every 6h (global-regional) up to 1h (regional-local) by one-way nesting, meteorology and chemistry is determined simultaneously (on-line).
A summer smog episode in 1994 was chosen for a first application of the mesoscale part of the model system (REMO-GESIMA). Preliminary results focussing on ozone prediction and scale dependence of several trace gas distributions are subject of interest. For the future it is planed to use the complete model hierarchy for analyzing climate and emission szenarios based on global simulations with the climate model ECHAM.

ON THE MODELLING OF CLIMATOLOGICAL CHARACTERISTICS OF PHOTOCHEMICAL SMOG IN BOHEMIAN BASIN

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The transport of air pollution on the regional scale (Bohemian region) is presented. The results of Charles University puff model for the imission assessment are used to give information on the concentration fields of ozone, nitrogen oxides and other ozone precursors. Current version of the model covers up to 16 compounds and it is based on trajectory computation using climatological wind roses and puff interaction both by means of Gaussian diffusion mixing and chemical reactions of species mentioned above. The alternative approach in terms of episodes studies can be solved as well, i.e. appropriate meteorological data can be used to estimate immision characteristics both for episodes analysis and, in case of connection to meteorological model forecast, the prediction of future air quality conditions.

ADAPTIVE PARCEL ADVECTION

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We present a method for performing trajectory analyses using an adaptive irregular mesh to allow refinement of the resolution of the flow. We keep track of nearest neighbours using Delaunay triangulation. Where parcel densities drop below a critical value, extra parcels can be added. Similarly parcels can be removed where the density exceeds a threshold. The critical value can be set using geographical information, (e.g. more parcels in the Northern hemisphere), dynamical quantities (e.g. shear in the flow field), tracer gradients, or other desired parameters. Arbitrary moving boundaries can be included to confine the parcels to a pre-defined region. Variable timesteps are incorporated to allow for the changes in resolution from place to place. The technique can be used in two or three dimensions. We compare two-dimensional results with contour advection calculations by concentrating the parcel density close to a fixed value of a tracer initialized using the potential vorticity on an isentropic surface. The potential for extension of the method to a full dynamical model will be discussed.

HIGH RESOLUTION FORECASTS OF POLAR STRATOSPHERIC OZONE USING THE CANADIAN GLOBAL ENVIRONMENTAL MULTISCALE MODEL

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Preliminary high resolution forecasts of polar stratospheric ozone are presented using the Global Environmental Model (GEM), an innovative model operationally used at the Canadian Meteorological Center. Here we use it in a regional configuration where the resolution is focused over either one of the polar regions, to study the effect of resolution on a simple stratospheric ozone chemistry. Both the sensitivity to the horizontal and vertical resolutions are examined by considering uniform 50 km and 25 km horizontal meshes over the area of interest, and by increasing the number of vertical levels in the stratosphere. The UKMO analyses are used to initialize the dynamical variables of the model while analyses based on total ozone data from the Global Ozone Monitoring Experiment (GOME) provide the initial conditions for chemistry. These univariate analyses of ozone were obtained with a 3D-variational assimilation (3D-var) developed out of the CMC operational 3D-var. The EOF associated to these analyses are also presented to assess the quality of the assimilation system.

RELATIONSHIP BETWEEN METEOROLOGICAL PARAMETERS AND SYNOPTIC CONDITIONS WITH EPISODIC PERIODS AT SANTA CRUZ DE TENERIFE (CANARY ISLANDS)

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Through the use of the data provided by an urban pollutant measurement station placed close to a refinery plant at Santa Cruz de Tenerife (Spain), several high pollutant concentration episodes have been analysed. The data provided by a captive balloon have been plotted on a Skew T û Log p thermodynamic diagram to describe the typical conditions of the lower layers of the atmosphere for each day analysed. Once these conditions have been determined, the synoptic patterns related to all these situations have been identified. A S-SE wind flow related to a high-pressure area placed at the Saharian area gives a subsidence inversion at the lower layers of the atmosphere. Both features depict the typical conditions related to these episodic situations.

OBSERVATION OF ATMOSPHERIC BOUNDARY LAYER CHARACTERISTICS OVER AN URBAN SITE

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The diurnal evolution of urban boundary layer over the central area of Rome was observed by the simultaneous and co-located operation of a Doppler sodar and a microwave ratiometer. The Doppler sodar was configured to provide a wind profile up to about 900 m for every 6 s with a height resolution of 27 m, and a time-height picture of the thermal structure of the urban boundary layer. The radiometer provided a temperature profile up to 600 m for every 120 s with a height resolution of 50 m. The experiment was conducted for a period of 30 days in the years 1996 and 1997. Although the daytime urban boundary layer was mostly characterized by the development of thermal plume structures up to a height of about 700 m, the nocturnal urban boundary layer showed a variety of features including the occurrence of Kelvin-Helmholtz waves, solitary-type waves, multiple-layers, etc. The occurrence of surface-based inversions was found to be rare. The height of the urban boundary laye! r during night-time was around 300 m and was near-adiabatic to isothermal in character. Some typical case studies are discussed.

SENSITIVITY OF OZONE PHOTOCHEMISTRY IN A POLLUTED AREA

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We study the sensitivity of ozone concentrations in an urban area to several parameters using a chemistry-transport box model. First, the influence of meteorological factors such as mean wind intensity, cloudiness and mixed-layer height is examined. Then, various upstream emission rates of nitrogen oxides and hydrocarbons are considered. Finally, we take into account different vertical mixing processes - namely local vs non-local processes - within the urban boundary-layer using the transilient theory approach. The effects of these parameters are studied with respect to the mean chemical reactivity as well as the existence of low and high NOx photochemical states in the urban boundary-layer.

A STUDY OF LAGRANGIAN TRANSPORT IN A WIND DRIVEN, 3-LAYER, EDDY-RESOLVING GENERAL CIRCULATION MODEL USING DYNAMICAL SYSTEMS THEORY

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We study the flow obtained from a 3-layer, eddy-resolving general circulation model subject to an applied wind stress curl. For this model we will consider transport between the northern and southern "gyres" separated by a jet. We will focus on the importance of invariant manifolds in forming geometric structures that govern transport. By "govern", we mean they can be used to compute Lagrangian transport quantities, both deterministic and statistical. We will consider periodic, quasiperiodic, and chaotic velocity fields, and thus assess the effectiveness of dynamical systems techniques in flows with progressively more spatio-temporal complexity. The significance of invariant manifolds as signatures of specific "events", such as rings pinching off from a meansering jet, will also be discussed. The relation of these concepts to potential vorticity dynamics be considered.
This research is supported by the Office of Naval Research through contract number NOOO14-97-1-0071.

STRATOSPHERIC OZONE, NITROGEN DIOXIDE and TEMPERATURE MEASUREMENTS at (44N, 11E) DURING 1996-'97

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The future trend of stratospheric ozone at mid and low latitudes is subject of increasing scientific interest. It is a subsequent of the need to clarify better the ozone loses caused by the local processes from the loses invoked by horizontal or vertical transport or from other factors contributing to ozone depletion.
The present paper deals with ground-base measurements of stratospheric ozone, nitrogen dioxide and temperature profile carried out during two years period. The stratospheric ozone and temperature data are collected by means of ECC and temperature sensors mounted on sondes, launched regularly at St.P.Capofiume(44.65N, 11.5N) WMO #297station. The lidar measurements at Brasimone (44.18N, 10.7E) supply upper stratosphere and low mesosphere temperature data. NO_2 data are provided from DOAS measurements in 407÷460nm spectral interval, carried out in Bologna (44.5N, 11.28E) and Mt.Cimone (44.2N, 10.5E)
The obtained experimental data are analysed and compared to satellite data and models predictions to look for transport and dynamic influence upon seasonal ozone variations.

A comparison of flight measurements from Summer '97 with TOMCAT

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In the summer 1997 a large number of aircarft flights took place over the North Atlantic ocean looking at the transport of pollutants from continental regions. The flights were for a number of campaigns including the NERC ACSOE. Measurements of important tropospheric species were made, including ozone, NOx, and carbon monoxide. Our Cambridge off-line 3-D tropospheric model, TOMCAT, was compared directly with the measurements made along flight tracks. TOMCAT has a detailed description of tropospheric chemistry. ECMWF meteorological analyses are used to force the model transport, for the period June to October 1997.
The flights were made in airmasses of different origin exhibiting different chemical signatures.

ATMOSPHERIC OZONE LINE OBSERVATIONS IN A FREQUENCY RANGE OF 90-110 GHZ.

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The results of ozone line observations conducted at Nizhny Novgorod (Russia) during 1996-97 are presented. 3^{mm} spectral line radiometer has been employed with the frequency resolution of 2 MHz and system noise temperature of 1200 K. 4 ozone lines were observed with the resonant frequencies of 96228, 101736, 103878 and 110836 GHz as the most intensive lines in operating waveband. Two first lines are observed systematically since February, 1996, till present time. The main objective of this project is to obtain the reciprocal intensities of ozone lines belonging to different transitions. Such measurements are supposed to be informative on the energy levels distribution of ozone molecules. In turn, this is important for an adequate estimation of ozone integral content and density profile. Average measured value of 101736/96228 line intensities ratio equals to 2.11±0.38 in comparison with its theoretical value of 1.8 (under LTR conditions). Two other ratios are 0.55±0.15 (103878 line) and 2.16±0.8 (110836 line) as regards to the same 96228 GHz line. Corresponding theoretical ratios are 0.6 and 2.5. Under observations, a significant deviation in ratios from their mean values were revealed presumably due to changes in physical conditions of atmosphere.

STRATOSPHERIC OZONE, NITROGEN DIOXIDE and TEMPERATURE MEASUREMENTS at (44N, 11E) DURING 1996-'97

I.Kostadinov[a,b], G.Giovanelli[b], F.Ravegnani[b], F.Evangelisti[b], P.Agostini[c], V.Cuzzola[c], P.Bonasoni[b]
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The present paper deals with ground-base measurements of stratospheric ozone, nitrogen dioxide and temperature profile carried out during two years period. The stratospheric ozone and temperature data are collected by means of ECC and temperature sensors mounted on sondes, launched regularly at St.P.Capofiume(44.65N, 11.5N) WMO #297station. The lidar measurements at Brasimone (44.18N, 10.7E) supply upper stratosphere and low mesosphere temperature data. NO_2 data are provided from DOAS measurements in 407÷460nm spectral interval, carried out in Bologna (44.5N, 11.28E) and Mt.Cimone (44.2N, 10.5E)
The obtained experimental data are analysed and compared to satellite data and models predictions to look for transport and dynamic influence upon seasonal ozone variations.

TELLURIC LINE OF N_2O AS AN INDICATOR OF ATMOSPHERIC TRANSPORT

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Nitrous oxide rotational lines were calculated using modern *in situ* data on its vertical distribution in Earth's atmosphere. These lines width and intensity subject to variations due to changes in N_2O density profile. In equatorial atmosphere, the mean value of line width equals to ~0.6 GHz insreasing up to ~0.9 GHz at moderate latitudes. This is a sequence of stratosphere being more rich of nitrous oxide in equatorial zone than at moderate latitudes owing to correspondent difference in convection. It implyes the N_2O line possible variations even at moderate latitudes, if the atmospheric transport has changed. This conclusion is supported with the results of N_2O line observations conducted at Nizhny Novgorod (Russia) during March-May of 1997. A 3-mm spectral radiometer was employed with the system temperature as high as 1200 K. The spectra were taken with 2 MHz resolution using the 30-channel filter spectrometer. Nitrous oxide rotational line ($J=3\rightarrow4$ transition corresponding to the resonant frequency of ~100,5 GHz) shows variations in its optical depth decrement measured at the frequency shift of 25 MHz from the resonance. During the observations, the decrement has increased by 3-5 times thus implying the significant redistribution of N_2O in a height region of 20÷55 km.

ENSURING ECOLOGICAL SAFETY OF MOTOR TRANSPORT IN URBAN OF CONDITIONS.

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Analysis of ecosystems condition is conducting: "Human being + car + environment" of a city as operating environment of motor transport. Adaptation of operation and system parameters of a fuel supply system of engines of modern cars to the concrete condition of their operating are determined. Structure analysis of mathematical model was made. Foundation of schemes and parameters of pollution indicator of air filters of engine fuel supply system are given. Specified technical actions on raising of ecological safety of modern cars in conditions of city.

On the importance of horizontal resolution and mixing in the modeling of the impact of aircraft emissions

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Mixing in the atmosphere is critical for the chemical evolution of the air contained in a plume. In particular, if the mixing is much faster than the timescale associated with chemistry, then it can be expected that the chemical state of the atmosphere will rapidly be equivalent whether the emissions were initially confined to a plume or instantaneously diluted. This dilution is implicitly related to the resolution at which the emissions are distributed in a model. Using a two dimensional chemistry/transport model, the problem of emissions mixing is studied in application to aircraft emissions. The modeled impact of aircraft emissions is shown to be dependent on the horizontal resolution at which the emissions are input into a model. Over the scales and for the conditions studied, the artificial dilution of the emissions due to their inadequate representation in coarse resolution models enables a more efficient reaction from NO_x (= $NO + NO_2$) to HNO_x (= $HNO_2 + HNO_3 + HNO_4$).

THE SWISS EPFL LIDAR IN THE EU WINTEX PILOT STUDY.

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The contribution of particulate matters as Mie scatters on LiDAR measurements is know to be an efficient tracer for the planetary boundary layer (PBL) height and development in polluted regions. A similar approach was proposed for the WINTEX study in March 97 at Marsta, Sweden, but for very clean boreal air conditions. In case of clouds covering at the height of the inversion layer, this aerosol LiDAR, operated at 532nm (total backscattered) and 355nm (polarized), could follow and retrieve this height, while in clear sky conditions, this PBL height tends to be more difficult to detect. Different meteo conditions will be presented, in particular the increase of the mixing height in the early afternoon due to the solar warming up of the ground.

AEROSOL STUDIES OVER NORTH ATLANTIC

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(1) P. P. Shirshov Institute of Oceanology, Moscow, (2) Alfred-Wegener-Institute fur Polar- und Meeresforschung.

Concentration and composition of aerosols in the North Atlantic were studied. There are data on particle sizes, contents of C, N, P, Si and Al, results of REM-EDAX analysis. It is showed that lithogenic component contents decrease and organic increase when going off the continents. Comparing of mineral component fluxes from atmosphere to the sea surface with rate of sediment accumulations ("absolute masses") on the floor evidences about important of the aerosols for the ocean sedimentation.

COUPLING BETWEEN CHEMISTRY AND MIXING IN A SIMPLE REACTION DIFFUSION SYSTEM

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For many years the environmental concentration of OH has been estimated from the differential change in concentrations of hydrocarbons of differing activity. The normal approach is based on the simplifying assumption that chemical and transport processes are seperated. However consideration of the continuity equation for a reactive species with source and sink terms leads to the conclusion that this simplifying assumption is not generally valid. In this paper new analytic solutions to some steady state diffusion equations will be presented and it will be shown that the seperability assumption of the observational OH studies is valid for all practical purposes. The concept of a coupling constant that is a simple function of the equation constants will be introduced. Finally it will be shown that when values of the coupling constant more appropriate to large scale numerical models are employed the likelyhood of interactions between chemical and mixing processes is much more likely.

ALIPHATIC HYDROCARBONS IN AEROSOLS OVER CENTRAL ATLANTIC

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It was studied distribution and composition of the alkane-naphtene fraction of the organic matter in aerosol samples collected on cross-section from the Mid-Atlantic Ridge (15 N) to Dakar. Contents of the organic carbon vary from 0.84 to 4.45 percents (dry matter), the hydrocarbons - from 91.0 to 1079 mkg/g, the n-alkanes - from 11.69 to 32.02 percents (from hydrocarbon content). Maximums of C25 , C27, C29, C31, C35 and C39 indicating on presence of higher-plant wax dominate in distribution of the biomarkers-n-alkanes. Ratios Pr/Ph vary from 0.87 to 4.17, C10-C 22/C 22-C 40 - from 0.04 to 0.26, CPI - from 2.32 to 6.29. Thus, the continents are source of the terrigenous lipids transported into central areas of North Atlantic by trade winds.

GREENHOUSE GASES IN THE LMD-Z GENERAL CIRCULATION MODEL

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M. Pham, D. Hauglustaine, C. Granier (Service d'Aéronomie, B102, Univ. Paris 6, 4, place Jussieu, 75252 Paris cedex 05, France)

In order to investigate the climate effect of greenhouse gases in an interactive way, greenhouse gases have been introduced in the new version of the general circulation model LMD-Z developed by the Laboratoire de Météorologie Dynamique (LMD).
This preliminary study presents the distributions of CH4, N2O, CFC11, and CFC12 as simulated by LMD-Z.
Surface emissions map for these gases are provided by the up-dated emissions inventories of GEIA and EDGAR.
In this version, chemical and photochemical sinks of the concerned species are calculated off-line with the IMAGES (Intermediate Model for the Annual and Global Evolution of Species) OH distributions and the photodissociation tables obtained with the model MOZART (Model of OZone And Related chemical Tracers). Wet and dry deposition are also taken into account.

SIMULATION OF TRACE-GAS DISTRIBUTIONS WITH THE UIUC 3-D ATMOSPHERIC CHEMICAL-TRANSPORT MODEL AND COMPARISON OF SOURCE GAS DISTRIBUTIONS WITH OBSERVATIONS

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The study of the interaction between climate and chemistry requires the development of fast and accurate submodels that describe photochemical processes and gas transport in the atmosphere. Due to computer time constraints, a number of parameterizations have to be used in such submodels. Accordingly, a detailed validation of the chemical and transport routines should be carried out. One of the best ways of validation is to compare the simulated gas species distributions with satellite climatological datasets. Here we present the 3-D UIUC Atmospheric Chemical Transport model. The model consists of three submodels: (1) A hybrid transport routine, (2) a photochemical routine, and (3) circulation fields generated by the our 3-D 24-layer AGCM. The results of an 8-year steady-state model run are analyzed and the distributions of the long-lived species are compared with appropriate HALOE and CLAES datasets. The simulated monthly zonal-mean mixing ratios of long-lived species are in reasonable agreement with observational data. The correlation between the simulated and observed distributions of long-lived species and the tracer-to tracer correlation show the very good overall performance of the model.

LIGNIN AND PHENOLS IN AEROSOLS OVER CENTRAL ATLANTIC

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It was researched distribution and composition of the lignin and phenols over the Central Atlantic on cross- section (15 N). Content of the identified phenols varies from 35.6 to 588 mkg/g in air-dried matter (2.06-8.09 percents from organic carbon). Calculated content of lignin in the samples is from 83.5 to 3645 mkg/g (16.7-51.9 percents from organic carbon). Prevalence of the p-hydroxyl structures above the vanillin and syring ones is observed in all samples excluding the sample collected near Cape Verde Islands. That relation indicates on transportation by the air masses of large quantity of the plant sporopollenin in which p-hydroxyl structures are dominated. Vanillyl and syringyl structures are in the particles of the higher plant. All noticed components fall on the sea surface and through water column to the bottom sediments, where are preserved for a long time.

Investigation of high pollution episodes in background regions

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Russia)

The idea of this study was to investigate high pollution episodes in background regions for most anthropogenic substances Pb, Hg, Cd and benz(a)piren. The study was performed for Borovoe (North Kazahstan) and Lesnoe (Russia) stations.
In the work statistics was calculated, and back trajectory was selected which meets high concentrations.
As a result a relationship between concentrations at observation site and spatial source distribution was found, and environmental conditions in two background regions was compared.

MODELLING THE TURBULENT DISPERSION OF POLLUTANTS IN CITY STREETS

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We need to be able to compute the concentration of atmospheric pollutants in city streets so that we can estimate the impact of such pollution on the inhabitants, so that we can interpret the point measurements provided by static pollution monitors and so that we can estimate the flux of pollutants emitted by the urban environment into the external atmospheric boundary layer. In many practical cases it is possible to idealise a large street as a long, quasi-2D cavity bounded by relatively large buildings. The flow within the cavity is then driven principally by the wind blowing over the top of the cavity, and consists of one or more eddies (depending on the aspect ratio of the cavity) trapped within the cavity. This type of representation is known as a 'street canyon' model. We have developed a new street canyon model which is intermediate between large CFD codes and empirical expressions for the concentration of pollutants. The basic principle of the model is that the flow inside the cavity is computed using a combination of potential flow and fixed, point vortices. The transport and dispersion of material within the cavity is modelled by the advection-diffusion equation, solved by using a conformal transformation to map the physical domain onto the $\phi - \psi$ plane, where we can use standard solutions of the equation. This model gives very good agreement with experimental results for the concentration field in the cavity.

THE ROLE OF REGIONAL TRANSPORT IN URBAN PHOTOCHEMISTRY

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The influence of long-distance transport of ozone and its precursors from remote areas on the photochemical smog formation is examined in different respects. First we demonstrate that it is a dominant effect in the Paris area, which allows one to doubt about the impacts of local traffic restrictions during these episodes. Second we examine in a more general manner the modifications of the local chemical regimes induced by this long-distance transport and show that nox-sensitive photochemical production can happen in certain circumstances even, over a large city. We also examine the predictability of the ozone concentrations according to the previous considerations.

OA22 Biogeochemical processes in submarine hydrothermal systems along the Hellenic Volcanic Island Arc

Convener: Varnavas, S.
Co-Convener: Dando, P.R.

DEEP SUBMARINE GAS VENTS IN THE AEOLIAN OFFSHORE

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Consistent results, concerning the detection of hydrothermal vents in 300-500m water-depth, were obtained during two different cruises (1991 and 1996) offshore the Aeolian islands, by down-to-bottom CTD and water-sampling casts. Sea-water was collected in 10-L Niskin-type bottles mounted on a rosette in association with a Seabird CTD, a Seatech 0.25-m-pathlength transmissometer and a Datasonics altimeter. Thanks to the shipUs echo sounder, two events were recognised: the former, in 1991, produced a wide plume, inside which water samples were taken, but no anomalies were detected, excepting for NH_4^+ content, which highlights the presence of a water-vapour phase; the latter, in 1996, was observed as a plume diffusing horizontally at about -350m. No significant temperature/salinity anomalies were evident during both events. The near-fumarole casts taken in 1996 are characterised by disturbed light transmission profiles, as well as by Rfalse-bottomS outputs appearing at ~300-350 m down to the seafloor from the rosette-mounted altimeter. High CO_2 and CH_4 and low O_2 seawater concentrations were observed in correspondence with the detected anomalies. These preliminary results allow to discriminate the geothermal origin of the released fluids from an organic one. Accordingly a series of geological and environmental implications (e.g. the relationships with seismic and volcanic activity) will be the object of further investigations.

THE INFLUENCE OF HYDROTHERMAL PROCESSES TO THE LIPID COMPOSITION OF SEDIMENTS FROM THE HYDROTHERMAL AREA NEAR THE CAPE VERDE ISLANDS

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Sediment samples from the Cape Verde Islands basin and nearby hydrothermal area taken during the 1995 RV "Akademik Mstislav Keldysh" expedition were investigated for the amount and composition of their lipids. Sediment lipids (hydrocarbons, polar lipids, sterols, wax esters, sterol esters, free fatty acids and triacylglycerols) were analysed by means of Iatroscan device. First results on the lipid distribution in long sediment cores indicate a significant terrigenous input (the high wax ester content) at the upper layers of sediment column (to the 100 cm depth). The substantial change of lipid composition on the 195-205 cm horizon is probably caused by the change of sedimentation conditions. Below this layer the lipid composition shows a significant influence of marine source of organic matter. All lipid samples demonstrate the high degree of microbial alteration. In particular it is found for the samples from hydrothermal area, where intensive biogeochemical processes lead to the higher degree of organic matter transformation.

HYDROTHERMAL PLUME COMPOSITION AND DISTRIBUTION SOUTH OFF MILOS, AEGEAN SEA, GREECE

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The known intense hydrothermal activity on the sea floor around Milos emits large amounts of hydrothermal fluids which change the physical and chemical parameters of the sea water in confined plume regions, especially in respect to chemical composition of trace and main elements, temperature, pH, conductivity and particle content. During several field trips in 1996 and 1997, suspected plume regions have been monitored and measured by different methods such as the towed sensor package MINIBAT, CTD, moorings with sediment traps and current meters. Combined with chemical analyses of water and particulate samples, the data provide an outline of the distribution and buoyancy state of the hydrothermal plume and of the ratio of hydrothermal fluid to sea water. Furthermore, fluid-sea water reactions, particle fall out and scavenging of trace elements can be assessed.

HYDROCARBONS IN BOTTOM SEDIMENTS OF THE HYDROTHERMAL FIELD AT 14045'N ON THE MID-ATLANTIC RIDGE

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The distribution and composition of alkane- naphtenic hydrocarbons (HC) in two samples of bottom sediments taken in the hydrothermal zone at 14 45'N on the Mid-Atlantic Ridge have been investigated. The first sample (column of bottom sediments) was selected by gravity corer, another sample was taken using the "Mir" submersibles directly near to the "black smoker". The contents of HC in the column varies from 0.18 mkg/g up to 1.98 mkg/g of a dry deposit or from 0.01 organic carbon (Corg), and in the sample "Mir" - 0.32 mkg/g or 0.01 1.2 up to 1.7). The concentration of Corg varies from 0.05 samples GC data reveal the presence of naphtenic HC. In the upper (0- 10 cm.) layer the increasing of high-molecular alkanes share is observed. The common configuration and smooth character of the distribution n-alkanes C21-C39 reminds a curve petroleum HC distribution. It may be caused by migration of petroleum HC with hydrothermal fluxes. The high concentration of naphtenic HC in compare with n- alkanes C21-C39 and CPI-index testify to a high degree of organic matter transformation as the result of thermocatalytic processes in the upper layer of the bottom sediments.

COMPOSITIONAL AND MORPHOLOGICAL CHARACTERISATION OF PARTICULATE MATTER IN HYDROTHERMAL FIELDS OF THE HELLENIC VOLCANIC ARC.

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Hydrothermal waters have been collected by scuba diving from the following submarine hydrothermal fields along the Hellenic Volcanic Arc: i) Offshore Methana on the western sector of the Arc ii) Palaeochori Bay. Milos iii) Voudia Bay. Milos. iv)Kephalos Bay. Kos and v) Bros Thermi. Kos. The waters were filtered in the field using a vacuum pump system and membrane filters of 0.45µm pore size. At representative vents. sampling was carried out at different times of the day. Particulate matter separated on the membrane filters was described morphologically and was analysed for certain elements such as Fe. Mn. Cu. Pb. Cd. . Ba. Sr. Ca. Al and Li.
Gas flow and waterflow measurements were also carried out during sampling. Additionally. in situ measurements for pH. conductivity. dissolved oxygen and temperature were undertaken. The spatial and diurnal compositional variability of particulate matter is investigated in relation to the morphological and geological setting of the hydrothermal field along the Hellenic Volcanic Arc.

HYDROTHERMAL ACTIVITIES IN THE SARONIC GULF AND IN THE KOS-YALI WATERS, GREECE

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Geochemical and tectonic investigations on marine sediments were carried out in the Saronic gulf offshore Methana peninsula and near Moni island in the western part of the Hellenic Volcanic Island Arc and in the eastern part between the islands Kos and Yali. Regions of hydrothermal activity are either related to single fault lines or to intersections of fault systems. Prior to the field work, the tectonic structure in the marine environment and their extensions into the islands were studied to select the sampling areas. The results of the geochemical analyses suggest increased hydrothermal activity in an area between Methana and Moni and in Thiafi bay east of Methana. Significant increase in Fe, Cu, Zn, Ba, P and S takes place in this area. In Thiafi bay, methane emanations take place in shallow waters. Moreover, the rocks at the shore are intensively altered by sulphuric solutions. In the eastern part of the volcanic arc, a hydrothermal field is present south of Yali island and at Kephalos Bay near Kos island. Here we report as preliminary results significant increases in As, Zn and Cu compared to the other study areas.

GEOCHEMICAL GRADIENTS AND BIOGEOCHEMICAL PROCESSES IN SEDIMENTS AT HYDROTHERMAL VENTS OFF MILOS, AEGEAN SEA

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Selected shallow water hydrothermal vent systems in Paliochori Bay, off the island Milos in the Aegean Sea, were characterized in terms of the geochemical gradients in the permeable sedimentary environment and the transport processes across the sediment-water interface. The effect of the physical and geochemical conditions on the formation of chemical precipitates or bacterial mats at the sediment surface in the vent surrounding and on temperature controlled mineralisation processes (i. e. sulfate reduction rates, NH_4 production, CO_2 release) was investigated.
In-situ measurements of temperature, pH, redox-potential, H_2S and O_2 confirmed the shallow vent sites to be extreme environments of low pH and high temperature. The outflow of gas or hot fluid through the permeable sediment induced a convection cell of pore-water entrainment from deeper sediment layers to the surface and into the water column. Nutrients, metals, H_2S and CO_2 were transported upward from the sediment across an area of 4 m diameter around a single vent. The outflow was compensated by an inflow of oxygen rich water in an area surrounding the vent like a ring at 2 m distance to the centre. These geochemical conditions were reflected in the type and structure of precipitate or mat froming on the sediment surface. The unique setting of increased temperature and pore water transport not limited by diffusion significantly enhanced remineralization rates in certain areas.

ST15 Atmospheric ozone (joint with OA)

Convener: Hirschberg, M.-M.

01 Modelling and validation with satellite data

Convener: Vardavas, I.M.
Co-Convener: Taylor, F.W.

Measurement of middle atmospheric trace gases from the Sub-Millimeter Radiometer instrument aboard the Odin satellite.

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The Odin satellite is a common project to Sweden, France, Canada and Finland, with the main characteristics to observe alternatively the middle atmosphere and astrophysical sources. Two instruments will be operated onboard : the Sub-Millimeter Radiometer (SMR) consists of five microwave radiometers in millimeter and sub-millimeter wavelength ranges and an Optical Spectrograph and Infrared Imaging System (OSIRIS) will operate in uv-visible and infrared wavelength ranges. The launch is foreseen in October 1998. The atmospheric limb will be scanned from 10 to 100 km. The sub-millimeter emission lines of trace gases will be measured at frequencies ranging from 480 to 580 GHz. We present the Odin mission and the sub-millimeter retrieval algorithm based on the Optimal Estimation Method. The characterisation of the errors and their impacts onto the retrieved profiles are also discussed. Retrieval budgets for O_3, ClO, H_2O, HNO_3 are finally shown.

THE MSDOL PROJECT: ASSIMILATION OF GOMOS OZONE DATA IN A 3-D CHEMISTRY-TRANSPORT MODEL

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In the frame of the preparation of the use of ENVISAT data, the Environment and Climate Programme of the EEC is supporting the MSDOL project: Monitoring of the Stratospheric Depletion of the Ozone Layer. The purpose is to assimilate the 400 vertical profiles of Ozone recorded each day by the experiment GOMOS in a 3-D chemistry-transport model, where the winds are derived from the ECMWF analysis for the lower part of the stratosphere. The sequentially assimilated model will better represent the reality since all single measurements are extrapolated in time through chemistry and transport. The assimilated model will serve at least two purpose : the comparison with other data sets, and the estimate of the evolution of ozone as a function of time and space.
The 3-D model is derived from the stratospheric chemistry-transport Rose model, in which the internally generated dynamics is replaced by the actual wind field. The first results with simulated GOMOS data will be presented.

INVERSION OF OZONE PROFILES FROM HIGH RESOLUTION IASI SPECTRA.

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The method used to extract ozone profile is based on the minimization of observed and calculated spectra in the 9.6 micron ozone band. The aim of the inversion is to estimate the profiles' accuracy and height resolution achievable with IASI spectra. Synthetic spectra calculated with the 4A-93 line by line model and transformed by the instrumental transfer function are used as observations. Inversions in tropical and mid-latitude conditions provide relative accuracies of 10% over a set of nine layers.

Stratosphere-Troposphere exchange: case studies recorded at Mt.Cimone during VOTALP project

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In order to point out and study the stratospheric/upper tropospheric transport of ozone rich air masses in the lower troposphere, continuous measurements of several parameters are undertaken at four mountain peaks, Jungfraujoch, Sonnblick, Zugspitze and Mt.Cimone during the European Community VOTALP project (Vertical Ozone Transports in the Alps).
Several high values of surface ozone concentration due to vertical stratospheric-tropospheric exchange have been recorded in these mountain peak stations. This work presents and analyses data concerning the Mt.Cimone ground-based station, which is the highest peak of the Italian Northern Apennines and the most representative WMO-GAW site in Italy.
Episodes of vertical exchange in the lower stratosphere, as tropopause folding, or in the upper troposphere, as down draft transport, have been recorded at Mt.Cimone since march 1996 and subsequently studied. In fact the comparison between the trends of different background trace gases at a mountain baseline station, the weather situations and the backward trajectory analyses can bring to light these events and can be very useful for a better knowledge of transport phenomena.
Correlation between high level of ozone concentration, chemical and meteorological parameters and three-dimensional backward trajectories relative to same events are shown.

OZONE VERTICAL DISTRIBUTIONS FROM GOME/ERS-2 SATELLITE DATA - II: OBSERVATIONS IN THE ARCTIC WINTERS 1996/97 AND 97/98

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The discovery of the Antarctic ozone hole in 1985 led to much scientific and public debate. A similar O3 loss above the Arctic was initially considered less likely because of the different dynamics of the Arctic polar vortex.
The retrieval program FURM, developed at the Institute of Remote Sensing in Bremen, is used to derive vertical ozone profiles from GOME satellite data on a near-global scale. Observations of the ozone content in different layers of the atmosphere for the Northern hemisphere during the Arctic winters 1996/97 and 1997/98 will be presented and discussed. By correlating the ozone distribution to meteorological parameters and to the distribution of other trace gases it is possible to attribute ozone variations to dynamical and/or chemical causes. The measurements of winter 96/97 seem to indicate that processes similar to those leading to the Antarctic ozone hole can take place in the Arctic.

EFFECT OF HOBR ON CATALYTIC DESTRUCTION OF OZONE IN THE LOWER STRATOSPHERE OF MIDLATITUDES, MODEL STUDIES INITIALIZED WITH UARS/HALOE DATA

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A photochemical box model on trajectories initialized with UARS/HALOE data for ozone and key species setting constraints to its catalytic destruction cycles is used to look for the sensitivity of ozone net destruction rates to the photolysis of HOBr including heterogeneous chemistry. Here we use the faster photolysis rates recently measured in our laboratory and compare that with older recommendations and a case where HOBr is neglected at all. It is demonstrated that especially in case of large sulfate aerosol surface density (Pinatubo) the effect of bromine induced reduced NOx and enhanced HOx significantly increases the net ozone destruction rates. Examples will be given for different years from 1992 to 1997 with focus on midlatitude summer. Preference is given to cases where the forward trajectories match the locations of other HALOE observations for validation.

TROPOSPHERIC OZONE AND ITS PRECURSORS: IMG MEASUREMENTS AND ATMOSPHERIC MODELS

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Global scale measurements of infrared absorbing trace gases were performed by the IMG remote sensor, which was launched onboard the ADEOS platform in August 96 and stopped operating after 10 months. IMG uses a Fourier transform interferometer to record the terrestrial thermal infrared radiation and provides atmospheric spectra from which O_3, CO and CH_4 may be measured. The nadir-viewing mode of the instrument allows to retrieve total column amounts each 86 km along the track of the satellite.

These measurements have been compared to the results provided by the three-dimensional chemistry-transport models IMAGES and MOZART. The differences between measurements and models have been analyzed for O_3 and its main precursors CO and CH_4, and the possible sources of discrepancies will be discussed.

CALCULATING THE FUTURE DEVELOPMENT OF THE OZONE LAYER WITH A DYNAMIC-CHEMICAL GCM

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The coupled dynamic-chemical general circulation model ECHAM3/CHEM is employed to estimate the possible future development of the stratospheric ozone layer. For the year 2015, the adopted increase of greenhouse gas concentrations and the corresponding modification of the sea-surface temperature lead to a warming of the troposphere and a cooling of the stratosphere. Considering the decrease of chlorofluorocarbons in the model atmosphere, which follows the agreement of Copenhagen (1992), the assessment for the year 2015 indicates that the ozone layer will not homogeneously recover. Whereas in low and mid-latitudes an enhancement of ozone mixing ratios is obvious, no significant increase of stratospheric ozone is found in the polar regions during spring time, especially over the Antarctic.

THE VISUALIZATION AND VALIDATION OF GOME (ERS-2) TOTAL OZONE MEASUREMENTS USING GIS TECHNOLOGY

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A comparison of limited set of ground-based (ozonometer M - 124) and satellite (GOME instrumentation, ERS-2) total ozone measurements over the northern-west and central regions of Russia in July and September-October of 1996 was accomplished. Satellite measurements systematically underestimate the total ozone in comparison with ground-based measurements, on the average, by 17 - 34 DU, depending on the comparison conditions. Permanent control of the quality of total ozone measurements testify to a lack of systematical measurement scale shift at the north-western Russian stations. Therefore it should be concluded that there is a systematical scale shift of the GOME total ozone measurements.

MODELED OZONE TRENDS

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A two-dimensional dynamical radiation-photochemical model of the troposphere and the stratosphere that embraces aerosol physics is used to examine the changes of ozone layer of the Earth occurring during the last 20 years. These changes are caused by anthropogenic atmospheric pollution, solar cycle variations of UV radiation flux, and sulfate aerosols from volcanic eruptions and regular flights of commercial aircraft. We show that the resulting effects of all the above factors is a negative ozone trend in the entire stratosphere. This trend is most significant in winter in the polar Northern and Southern areas. For example, for the $50°N - 60°N$ region at $45km$ altitude, the ozone trend is about -8% to -9% per decade. This trend fairly agrees with the ozone trend observed with SBUV and SBUV/2. The model values for the global annual average of total ozone (GAATO) computed for the range between $65°S$ and $65°N$ are in the good agreement with the experimental GAATO data obtained with TOMS during the period of 1979 through 1994. We show that the GAATO trend caused by anthropogenic atmospheric pollution is about -2.8% per decade. The solar UV flux variations in the course of the 11 year solar cycle contribute $\pm0.6\%$ in maximums (about 1.2% from the solar maximum to the minimum of the cycle). The sulfate aerosol increase as a result of the El Chichon and Mount Pinatubo eruptions leads to the local GAATO changes in 1983 and 1992 about -1.6% and -2.7%, respectively.

SIMULATION OF THE ATMOSPHERIC OZONE DISTRIBUTIONS WITH THE 2-D MODEL AND VALIDTIONS WITH HALOE AND TOMS DATA

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A two dimensional model of radiative, dynamical and photochemical processes in the stratosphere has been developed and used for study of the atmospheric ozone distributions. The model calculates stratospheric wind velocity components, air temperature and humidity; short- and long wave radiation fluxes, chemical species source-sink intensities and concentrations. Temperature, humidity and circulation in the troposphere are prescribed and taken from observations. Chemistry module calculates 38 species concentrations. The 16 long lived gases are transported. The fully implicit Newton-Raphson method is used for 22 short lived species. The heterogeneous reactions in/on sulfate and PSC particles are taken into account. The results of numerical simulations are compared with the HALOE measurements and the TOMS data. The comparison of the simulated and the HALOE stratospheric O_3 data has been made in tropical, mid, and high latitudes for all seasons. It shows that the overall agreement between model and measured fields is within 5-15% for almost whole stratosphere except the high latitudes of the winter hemisphere. This disagreement is a common problem for all 2-D models, which can not reproduce the planetary and gravity wave breaking processes over the high latitudes. The comparison of the simulated total ozone and TOMS data also will be presented.

LIGHTNING PRODUCTION OF NO_x AND ATMOSPHERIC OZONE

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For tropospheric chemistry lightning is a major source of NOx. NOx in turn affects the concentration of ozone in the atmosphere, which is an important greenhouse gas. In this study we estimated lightning production of NOx and its influence on distribution atmospheric ozone in the upper troposphere and the low stratosphere depends on global source strength. A two dimensional model of radiative, dynamical and photochemical processes in the stratosphere has been developed and used for. The transformations of 38 species are calculated in the chemical part of the model with Newton-Rafson scheme. About 100 gas-phase and 5 heterogeneous reactions on sulfate and PSC particles are included in the model. We compare NOx and NOy simulated by our 2-D model with available observations to choose suitable global lightning source of NOx. NOx produced by lightning flashes are distributed by latitude, altitude and season variations. Having generated our two-dimensional, time-dependent relative distribution of NOx emissions by lightning, we have made preliminary experiments with different total source of NOx (2-20Tg/year). It shows that concentrations of NOy and O_3 almost independent on global source strength of NOx in the stratosphere, but very important for upper troposphere.

APPLICATION OF MONTE CARLO SIMULATION OF MULTI SCATTERING RADIATION TRANSFEREE TO ERROR ANALYSIS OF EXTENDED BREWER UMKEHR METHOD FOR OZONE PROFILE DETERMINATION

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Umkehr method is applied at network of Brewer spectrophotometers to determinate the ozone vertical distribution. To improve its accuracy opportunities, an extended Brewer Umkehr method was proposed by authors. Two ways to employ multiscattering radiation transferee model in the retrieval algorithm of the extended Umkehr method are investigated. Both use the Monte Carlo numerical method of radiative transferee simulation. We applied the double local estimation method with physical sampling of the free path length without escape until two collisions occurred and take into account spherical geometry and polarization properties. The main deductions on the method accuracy are defined more exactly in comparison with single scattering modeling. Some new features are displayed in the lowest stratosphere.

VARIATIONAL ASSIMILATION OF OZONE TOTAL COLUMN SATELLITE DATA IN A 2D LAT-LON TRACER-TRANSPORT MODEL

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A 4D variational data assimilation method is described to derive global ozone distributions from total column ozone satellite measurements. The ozone columns are advected by a 2D tracer transport model, using ECMWF wind fields at a single pressure level. Special attention is paid to the modelling of the background error covariance and quality control. The time, latitude and season dependence of the forecast error are taken into account, resulting in a global error field at any instant in time that provides a local estimate of the accuracy of the assimilated field. We discuss the advantages of the variational approach over sequential assimilation schemes. One of the attractive features of the variational technique is its ability to incorporate measurements at later times $t > t_0$ in the analysis at time t_0. In this sense twice as much information is extracted from the sparse measurements.

ANNUAL VARIATION OF THE STATISTICAL LINK BETWEEN ZONALLY ASYMMETRIC TOTAL OZONE TREND AND DECADAL CHANGE IN DYNAMICS

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At the example of March it will be shown that upper tropospheric and lower stratospheric decadal change of dynamics during 1979 - 1992 distinctly influences the spatial distribution of zonally asymmetric (longitude dependent) decadal ozone change in mean latitudes of the northern hemisphere. These influences will be shown by spatial correlation of total ozone measurements from TOMS on board of Nimbus 7 and of Adeos together with NCEP geopotential height change of 300 hPa, found as a good indicator of dynamics in the called height region. The spatial regression between decadal ozone change and geopotential change is - 0.16 (DU/yr)/(gpm/yr), and is significant with more than 99 %. This diagnostic analysis is extended to all month of the year. In the annual variation these values vary between - 0.17 in spring and - 0.07 (DU/yr)/(gpm/yr) in autumn, in similarity to the annual variation of total ozone density, whereas the spatial correlation between decadal ozone change and geopotential height change is high in summer and relatively low (but still significant) in winter in similarity to the annual variation of the variability of dynamics.

LONG-TERM MONITORING OF STRATOSPHERIC OZONE AT THE OBSERVATOIRE DE HAUTE-PROVENCE USING GROUND-BASED AND SATELLITE INSTRUMENTS.

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A study of the long-term evolution of the stratospheric ozone at the Observatoire de Haute-Provence (43.9N, 5.7E) is performed using ground-based measurements from Dobson spectrophotometer, lidar, ozonesondes, and using SAGE II satellite measurements. Those experiments provide datasets with lengths of about 10 years, which allows the comparison of interannual variability of the ozone measured by the different instruments. A multi-parameter regression is used to extract the long-term evolution from other variations (seasonal variability, Quasi-Biennal Oscillation forcing) of total ozone and of vertical profiles from the different experiments between 1985 and 1995. The effects of volcanism and of the 11-year solar cycle on long-term evolution of ozone are studied too. Differences between the time series of the ozone residuals after the regression underline instrumental differences and possible instrumental sensitivity to the volcanic aerosols for some of them.

APPROXIMATE LIMB SOUNDING DATA INVERSION.

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The new effective approximate technique is presented. The mathematical basis of it is the asymptotic expansions techniques and Laplace integrals. Unknown atmospheric gas distribution is rough approximated by exponential function $f(r,\varphi)\exp(-\lambda r)$. Integral over a ray trajectory with the tangent point coordinates (p,φ) known from the limb occultation experiment is $I(p,\varphi) = \int f(r(x),\varphi(x))\exp(-\lambda r(x))\,dx$ where x is the local Cartesian coordinate along the trajectory. Using the Laplace integral asymptotic expansion we get approximate equation which can be used to retrieve unknown function $f(r,\varphi)$:

$$I(p,\varphi) \approx \exp(-\lambda p)\left\{\sqrt{\frac{2\pi p}{\lambda}}f + \frac{3}{8\lambda}\sqrt{\frac{2\pi}{\lambda p}}f + \frac{1}{\lambda}\sqrt{\frac{\pi p}{2\lambda}}\frac{\partial f}{\partial r} + \frac{1}{\lambda}\sqrt{\frac{\pi}{2\lambda p}}\frac{\partial^2 f}{\partial \varphi^2} + O\left(\lambda^{-5/2}\right)\right\}.$$

This approach has several advantages. It's regular, because the solution of this differential equation continuously depends on left-hand side and any additional information can be integrated into retrieval scheme through boundary and other conditions for the unknown function. Application of this technique to occultation measurements of different physical effects, such as refraction, microwave phase shift, absorption, airglow emission, refractional attenuation etc. are discussed. The results of the numerical simulation are presented. Application to the local spherical symmetry approximation (LSSA) results correction is also included in the report.

3-D global simulations of tropospheric O3 budget - results of the GIM/IGAC intercomparison 1997 exercise.

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The objective of the Tropospheric Ozone (O3) Global Model Intercomparison Exercise performed in 1997 was to systematically evaluate the capabilities of the current generation of 3-dimensional global models used for tropospheric O3 studies, and to identify key areas of uncertainty in our understanding of the tropospheric O3 budget. This exercise has been organised by GIM (Global Integration Modelling) part of the IGAC (International Global Atmospheric Chemistry) activity. The strategy was to investigate the coherence of the models and how do the model results compare to the real atmosphere. 12 global 3-dimensional Chemistry Transport Models have been participated at this exercise. These models differ in the parametrisation of the main processes controlling chemical tracer budgets i.e. transport by advection, diffusion and convection, chemistry (homogeneous and heterogeneous), wet and dry deposition, and emission of trace compounds by natural and anthropogenic sources. On the basis of these results, the uncertainties in tropospheric O3 budget and the performances of the models will be discussed and the differences will be analysed.

SIMULATIONS OF STRATOSPHERIC CONSTITUENTS IN A UNIFIED CLIMATE / FORECAST MODEL

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A high resolution three-dimensional general circulation model with stratospheric chemistry interacting with the model heating rates is integrated for a sequence of 10 day periods. The periods are chosen to coincide with low temperatures in the lower stratosphere when polar stratospheric clouds occurred. The initial conditions are taken from observations from the northern winters 1992-1998 and comparisons are made between simulations with different polar stratospheric cloud (PSC) schemes. Results are analysed, amongst other ways, in terms of the ozone change on the 475 K isentropic surface for air parcels within the vortex, as defined by equivalent latitude. The effects of the different PSC schemes and of the different time of year on the constituent concentrations are discussed.

ASSIMILATION OF THE UARS/MLS OZONE MEASUREMENTS IN A 3-D STRATOSPHERIC CHEMISTRY TRANSPORT MODEL

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A sequential data assimilation scheme has been implemented in the 3-D global stratospheric chemistry transport model ROSE (Rose and Brasseur, 1989). The model contains an extensive photochemical scheme and includes heterogeneous reactions. The UKMO stratospheric analysis data are employed for transport calculations.
Ozone profiles from the Microwave Limb Sounder (MLS) on board the Upper Atmospheric Research Satellite (UARS) were used in the assimilation. The obtained global distributions of ozone and other species will be presented.
The resulting three-dimensional ozone distributions were used to calculate the total stratospheric ozone column. Using the ozone climatology from Fortuin et al. (1995) the total ozone column was computed and compared with total ozone measurements from the Global Ozone Monitoring Experiment (GOME) on board the European Remote Sensing satellite (ERS-2). Results of these comparisons will be presented and discussed.

Storm track signature in total ozone during the northern hemisphere winter

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Total ozone has long been known to correlate with synoptic eddy activity, low total ozone being associated with anticyclonic conditions. Such eddy activity is particularly intense over the storm track regions of the North Atlantic and Pacific oceans during boreal winter. An Eulerian diagnostic was introduced by Blackmon et al. [1977] to investigate storm tracks, based on band-pass filtering the 500 mb geopotential height for synoptic time scales. Wintertime satellite observations of total ozone by the TOMS instrument are analyzed using the same time-filtering approach. Climatological storm track signatures in total ozone are described. The North Pacific signature is weaker than over the North Atlantic, and the cause of this asymmetry is explored. In the winter 1996/97, the Atlantic storm track was displaced westward and poleward due to persistent anticyclonic conditions over western Europe. Total ozone fluctuations on synoptic time scales were hence reduced over western Europe.

Validation of ground-based microwave measurements at the Bordeaux Observatory, France

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Ozone measurements are carried out by a ground-based microwave radiometer at the Bordeaux Observatory, (45°N, France). This instrument tuned to the 110.836 GHz ozone line uses a beam switching observation method. Ozone profiles are retrieved using the optimal estimation method in the altitude range 25-75 km. An error analysis has been completed, including measurement, model parameters and smoothing errors. Validation of results obtained over a three-year period (1995-1997) is presented. It consist of comparing Bordeaux retrieved profiles with ozone profiles provided by i) ground-based microwave measurements from the Bern University, Switzerland, ii) ground-based lidar measurements from the Observatoire de Haute Provence, France, iii) measurements, selected over the station, by the Microwave Limb Sounder instrument aboard the Upper Atmosphere Research Satellite, and finally iv) results from the 3-D SLIMCAT model.

DESIGN OF A NEW DIAL SYSTEM FOR TROPOSPHERIC AND LOWER STRATOSPHERIC OZONE MONITORING IN NORTHEN GREECE

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A new ozone DIAL system has been designed for tropospheric and lower stratospheric ozone monitoring in Northen Greece. The system is based on a quadrupled pulsed Nd:YAG laser and the Raman shifting technique in deuterium (D_2) and hydrogen (H_2) gases. The lidar system emits simultaneously 4 wavelegths (266 nm, 289 nm, 299 nm and 316 nm) using a single Raman cell. The optical receiving system is based on a 50 cm concave telescope which is coupled to a specially conceived spectrometer through a quartz optical fiber. This lidar system uses state-of-the-art analogue (12 bits-40 MHz) and photon counting (250 MHz) real-time detection systems able to measure lidar signals up 20 km height. Ozone vertical profiles are measured from 1 km up to 16 km height with a 50 m average spatial resolution and a 1-minute temporal resolution. In this paper the major technical characteristics of the new lidar system will be presented. The system is foreseen to provide the first ozone vertical profiles on May 1998 during the Photochemical Activity and Ultraviolet Radiation (PAUR II) European Campaign.

GLOBAL ATMOSPHERIC MONITORING WITH SCIAMACHY

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SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric CHartographY) is a space based spectrometer designed to measure sunlight transmitted, reflected and scattered by the Earth atmosphere or surface. It is a contribution to the ENVISAT-1 satellite to be launched in late 1999.
SCIAMACHY measurements will provide amounts and distribution of O_3, BrO, OClO, ClO, SO_2, H_2CO, NO_2, CO, CO_2, CH_4, H_2O, N_2O, p, T, aerosol, radiation, cloud cover and cloud top height from atmospheric measurements in nadir, limb and occultation geometry. By the combination of the near simultaneous limb and nadir observations SCIAMACHY is one of a limited number of instruments which is able to detect tropospheric column amounts of O_3, NO_2, CO, CH_4, H_2O, N_2O, SO_2, and H_2CO down to the planetary boundary layer under cloud free conditions.
SCIAMACHY will provide new insight into the global behaviour of the troposphere and the stratosphere. Because of its wide range of applications SCIAMACHY is a good candidate instrument for any future global monitoring system.

SENSITIVITY OF PHOTOLYSIS RATES J(O¹D) AND J(NO₂) TO DIFFERENT ATMOSPHERIC CONDITIONS

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Modeling of the chemistry of the lower atmosphere requires photolysis rates of certain gases based on a radiation field which includes ozone absorption, molecular scattering and surface reflection. Meteorological conditions like clouds and aerosols also affect the actinic flux and have to be considered. Photolysis of ozone ($\lambda \leq 320$nm) is one of the most relevant primary sources for hydroxyl radicals via the reaction of $O(^1D)$ with H_2O. OH radicals are important for the tropospheric chemistry where they are involved in the oxidative composition of many man-made and natural trace gases such as CO, CH_4, SO_2 and CH_3CCl_3. The photodissociation of NO_2 ($\lambda \leq 420$ nm) provides the oxygen atoms required for photochemical ozone formation in the troposphere.
We used the model TUV (Madronich, 1997) to make modeling of the photolysis frequencies $J(O^1D)$ and $J(NO_2)$ and the sensitivity to solar zenith angle, overhead ozone column, cloud cover, aerosol loading, temperature, pressure and surface albedo is examined. A comparison with measurements of the photolysis rates under a variety of conditions commonly found in the troposphere will be used to stabilize the modeled data.

THREE-DIMENSIONAL SIMULATIONS OF OZONE IN THE STRATOSPHERE AND COMPARISON WITH UARS DATA

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A 3-D Atmospheric Chemical Transport model has been developed and used for the simulation of present-day trace-gas distributions in the troposphere and stratosphere. A 10-year-long steady-state model run for 1995 boundary conditions and circulation fields derived from the 24-layer UIUC AGCM has been carried out. The simulated distributions of ozone and radical species (e.g., NO,NO2, and ClO), which are responsible for the ozone destruction in the stratosphere, are compared with available observations made by the HALOE, CLAES and MLS instruments onboard UARS satellite. The comparison is carried out for monthly zonal-mean climatology for particular days and locations, and the correlations between different species derived from the simulated and measured data are calculated. The results of this comparison show reasonable agreement (within 30%) of the simulated and measured monthly zonal-mean ozone distributions, although the location of the simulated maximum in the ozone distribution is generally lower (about 2-3 km) than derived from satellite data. A substantial disagreement between the simulated and measured data occurs for particular days and locations, when the synoptic-scale variability of the ozone cannot be simulated by the model driven by the climatological circulation produced by the AGCM. The influence of the choice of chemical reaction set on the stratospheric ozone is estimated with additional short-term model runs.

OZONE VERTICAL DISTRIBUTIONS FROM GOME/ERS-2 SATELLITE DATA - I: COMPARISON WITH INDEPENDENT MEASUREMENTS

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The GOME (Global Ozone Monitoring Experiment) launched aboard ESA's 2nd European Remote Sensing Satellite (ERS-2) in April 1995 is part of the international scientific effort to improve our understanding of the natural and anthropogenic influences on the global ozone distributions. GOME is a nadir-viewing grating spectrometer covering the wavelength range 240-790 nm with a moderate spectral resolution of 0.2-0.4 nm. With the current scan strategy global coverage at the equator is achieved within three days, the horizontal resolution being 960kmx100km.
At the Institute of Remote Sensing the FUll Retrieval Method (FURM) was developed to derive vertical ozone distributions from GOME data. FURM is based on an optimized optimal estimation method, which in this form is being used in satellite remote sensing for the first time. The vertical resolution that can be achieved is of the order of 6-10km in the lower and upper stratosphere. For cloud free or low clouds scenes the tropospheric column can also be retrieved. The quality of the inferred profiles will be assessed by comparing them to selected ozonesonde profiles and other independent measurements.

ST15 Atmospheric ozone (jiont with OA)

Convener: Hirschberg, M.-M.

02 Polar ozone

Convener: Krivolutsky, A.A.

CLIMATOLOGY OF THE REPROBUS CHEMISTRY-TRANSPORT MODEL COUPLED TO THE ARPEGE GENERAL CIRCULATION MODEL

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The REPROBUS Chemistry-Transport Model calculates the chemistry of the stratosphere whereas stratospheric dynamics is determined by the climate version of the ARPEGE General Circulation Model. Both models are coupled : ozone calculated by the full photochemical package of REPROBUS is taken into account in the radiative budget calculation of ARPEGE which in turn provides REPROBUS with temperature and winds. This allows interactive coupling between dynamics and chemistry. The strongest effect of chemical feedback upon dynamics is a modulation of the Antarctic vortex, related to the ozone depletion amplitude. Both models are run for several years for the current atmosphere and for the atmosphere of year 2015. The climatologies of both atmospheres will be presented and discussed, with particular emphasis upon the « Antarctic ozone hole » in the southern hemisphere, and stratospheric global warming occurences in the northern hemisphere. The climatology of the simulated current atmosphere will be compared to the Total Ozone Mapping Spectrometer (TOMS) and Upper Atmosphere Research Satellite (UARS) data.

THE ROLE OF WATER VAPOUR PHOTODISSOCIATION ON MESOPAUSE OZONE

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A one-dimensional atmospheric photochemical model is used to examine the structure of the global mean vertical ozone profile and its nighttime to daytime variation in the upper atmosphere. Two distinct ozone layers are predicted, separated by a sharp drop in the ozone concentration near the mesopause. This naturally occurring mesopause ozone deep minimum is primarily produced by the rapid increase in the destruction of water vapour, and hence increase in HO_x, at altitudes between 80 and 85 km, a region where water vapour photodissociation by ultraviolet radiation of the solar Lyman-alpha line is significant and where the supply of water vapour is maintained by methane oxidation even for very dry conditions at the tropospheric-stratospheric exchange region. The model indicates that the depth of the mesopause ozone minimum is limited by the efficiency with which inactive molecular hydrogen is produced, either by the conversion of atomic hydrogen to molecular hydrogen via one of the reaction channels of H with HO_2 or by Lyman-alpha photodissociation of water vapour via the channel that leads to the production of molecular hydrogen. The sensitivity of mesopause ozone to solar cycle uv flux variations and to increasing greenhouse gases is also examined. Recent observational evidence supports the predictions of the model.

POLAR OZONE AS OBSERVED BY ADEOS ILAS AND TOMS INSTRUMENTS

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The ILAS and TOMS instruments measured respectively the ozone vertical distribution and total ozone amounts during the 1996-1997 polar summer. Between 50 S and the south pole total ozone is characterized by a maximum centered near 60S and a decrease to a minimum of 200 to 250 DU at the south pole. Total ozone amount changes from month to month during the summer. Ozone amounts vary longitudinally with indication of wave structure. There is evidence of total ozone circumpolar transport and latitudinal transport toward the pole. ILAS ozone observations are confined to the 60 to 70 S latitude region. These profiles show altitude structure, which varies with time and location. Using back trajectory analysis and calculated pv maps, it is possible to trace the origins of stratospheric ozone at different altitudes ie. potential temperature surfaces. There is an indication of transport from lower to higher latitudes existing at some vertical levels and not others in agreement with ILAS observations of profile shape changes. This type of analysis can be used to evaluate the fine structure in the ILAS profiles. Total ozone amounts as observed by TOMS and ILAS are employed to validate ILAS. Northern hemisphere polar ozone data in the early spring are also analyzed.

MODELED OZONE LOSS IN THE ARCTIC STRATOSPHERE IN COMPARISON TO RESULTS OF THE MATCH EXPERIMENTS

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The Match technique determines chemical ozone depletion in the Arctic polar vortex from an analysis of pairs of ozone soundings probing the same airparcel at two different points of a calculated trajectory. It allows a quantitative comparison of the observed ozone loss rates with model results because the exposure of the probed airmasses to sunlight is known. We use a photochemical box model to simulate the Match experiments of the winters 1991/92 and 1994/95. The model severely underestimates the early winter ozone loss. Extensive sensitivity studies for the winter 1991/92 show that the discrepancy between model and Match results can not be explained by uncertainties of the model parameters.

A DISCUSSION ON THE VARIABILITY OF ATMOSPHERIC TRACE GAS CONCENTRATIONS AND OTHER HIGH LATITUDE PHENOMENA

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Routine measurements of atmospheric trace gas concentrations by ground-based monitoring optical instruments at high latitude facilitate studies of possible influences of different phenomena on atmospheric trace gases. In this study we use data from UV/visible DOAS instruments operated at the Swedish Institute of Space Physics in Kiruna in order to discuss the variability of O3, NO2, OClO, and BrO over a one-year period.
The initial study includes a discussion on the location of the polar vortex, the location and activity level of the auroral oval, cloudiness, and lightning. Only a few aspects of each individual high latitude phenomenon is quantified and related to the derived trace gas concentrations.

TOTAL OZONE CONTENT OVER MURMANSK

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Total ozone measurements have been performed by different organisations on a regular basis at Murmansk (φ=68.97^{0}N, λ=33.05^{0}E; Φ=64.5^{0}N, Λ=115.2^{0}E) since the beginning of observations in 1971 to 1997. All the data of ozone observations for the whole observation period are collected as a data base in the Geophysical Observatory Loparskaya. An initial analysis of collected data was implemented and it was noted that the total ozone content (TOC) at Murmansk during the last 27 years showed the decreasing of the one. A seasonal behaviour and other characteristics of TOC were obtained.

PSC LIDAR MEASUREMENTS INTERPRETATION BY A MIE MODEL

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PSC measurements from ALOMAR/RMR lidar has been classifyied in terms of backscatter measured at three wavelengths ($\beta_{aer}^{\lambda_{1,2,3}}$), Two values of lengthwave dependance of aerosol backscatter(Angstrom coefficient α) and Depolarisation (δ). The typical values of the optical parameters is different from previous classifications, especially for type Ib PSCs. A coherent behaviour of the α-β_{aer} relationship is found for each kind of PSC, but is slightly variable from mesurement to measurement. The first aim of this work is to define the sensitivity of optical measurements to changes in aerosol characteristics and to identify the cloud evolution in terms of size distribution parameters. To do this, β_{aer} and α are calculated by a Mie model with random selection of bulk parameters and refraction index inside the range for type Ib PSCs. Theoretical α and β_{aer} corresponding to measured ones are selected in order to characterise measured PSC's by random model parameters . Temperature has been measured simultaneously inside PSC by Raman Rotational technique during several events. Measured ($\beta_{aer}^{\lambda_{1,2,3}}$, α) and theoretical (size distribution average volume) aerosol parameters will be related to temperature changes.

OZONE MEASUREMENTS IN THE LOWER TROPOSPHERE OVER NY-ALESUND, SVALBARD (78°55'N, 11°53'E)

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Hourly surface ozone measurements made since 1991 at the Zeppelin mountain, Svalbard, using a UV-absorption ozone analyser are compared to coinciding ozone measurements from balloon borne electrochemical cell ozonesonde observations launched from nearby Ny-Alesund. By extending the surface ozone measurements with in-situ ozonesonde measurements, we attempt to establish the seasonal characteristics of ozone in the lower troposphere with respect to prevailing meteorological conditions and air-mass origin at different levels.

COMPARISON OF AIRBORNE LIDAR MEASUREMENTS WITH HIGH RESOLUTION TRACER TRANSPORT MODELS

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Stratospheric ozone and aerosol were measured during winter 94/95 in several campaigns with an airborne LIDAR system. The comprehensive set of vertical along-flight-track profiles inside. across and outside the polar vortex mirrors the development of the lower stratosphere during that winter. The LIDAR data are used to validate high resolution transport models which again complement the vertical along flight track information horizontally. This provides information about the height resolved ozone and aerosol distribution of the European middle and high latitudes. In this study a Contour Advection and a Domain Filling Trajectory code driven by winds from UKMO data assimilation are run to advect potential vorticity (PV) as air mass tracer. One of the most striking features of the measured ozone distributions is the pronounced small scale horizontal (~1°) and vertical (~1km) inhomogeneity with blob- and tilted stripe structures occurring throughout the winter in the lower stratosphere. It is shown that in many cases the filaments indicated thereby are reproduced by the models on various potential temperature levels. This confirms the relevance of dynamical processes peeling off narrow sheets of air from the vortex edge and subsequently transporting and diluting them to middle latitudes. Chemically induced ozone depletion previously reported for 21 March 1995 is confirmed and the transport of ozone depleted vortex air to mid-latitudes discussed.

Measurements of Stratospheric Ozone and Chlorine Monoxide over Ny-Ålesund, Spitsbergen, in 1997 and 1998

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Observations of stratospheric ozone and chlorine monoxide (ClO) are regularly being performed at the Arctic station of the "Network for the Detection of Stratospheric Change" (NDSC), using a ground based millimetre wave radiometer. While ozone has been operationally monitored since 1994 at an observation rate of about 20 profiles per day, ClO measurements are being restricted by the strong and variable absorption of tropospheric water vapour and the necessity of day and night time observations. The location of the observation site, Ny-Ålesund (78.9°N, 11.9°E), enabled us to take data inside the polar vortex in 1997. We observed enhanced levels of stratospheric ClO of up to 1.6 ppbv from late February to early April 1997 in the vicinity of 20 km of altitude. Considering diabatic processes, using our own ozone measurements for the calculation of atmospheric heating rates, we have derived chemical ozone loss rates of up to 20 ppbv/day in the same altitude range. A subsequent ozone loss of approximately 35% was measured over the complete ozone loss period. Besides details of this analysis we are presenting data of 1998 for both species.

POLAR STRATOSPERIC CLOUD MEASUREMENTS BY LIDAR AND BALLOON BORNE SONDES AT SODANKYLÄ IN 1996/1997

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Series of PSC measurements were performed at an Arctic site Sodankylä (67 °N, 26 °E) during the winter of 1996/1997. The instrumentation consisted of aerosol backscatter and depolarization lidar and balloon borne backscatter sondes. In many cases it was possible to obtain aerosol backscatter and depolarisation profiles quasi-simultaneously by both instruments. We present a summary of all PSC measurements performed during January-February 1997. During January 1997 PSC temperatures at 50 hPa were observed in 13 percent of all radiosonde launches, which is the lowest for the last 6 winters for this altitude. On January 22-23, 1997 we observed type II PSC with the measured temperatures 6-8K lower than the synoptic scale temperature. On the other hand, 3-dimensional mesoscale numerical weather prediction models used in our study, were able to present realistic analysis of the temporal development of cold areas over northern Scandinavia, formed as a result of lifting of isentropic surfaces by mountain waves.

ST15

SIMULATION OF THE DYNAMICS AND CHEMISTRY OF THE ARCTIC STRATOSPHERE DURING THE WINTERS 1995/96 AND 1996/97

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During the consecutive winters of 1995/96 and 1996/97 record low temperatures well below 195 K, the conventional threshold value for PSC-I formation, were observed in the lower arctic stratosphere. While the low temperatures in the former winter were caused by strong upper tropospheric blocking common to northern hemispheric winters, the latter showed a strong, less disturbed and persistent cold polar vortex, a feature usually observed in the antarctic winter stratosphere. In both winters the cold temperatures led to the formation of PSC's. The disturbance of the chlorine chemistry due to heterogeneous reactions and the subsequent ozone destruction resulted in unusually low ozone values in the northern hemisphere.
The aim of this study is to investigate the dynamical and chemical processes and their interaction during these episodes. A three dimensional mechanistic model of the middle atmosphere which is coupled with a chemistry and a transport module is used to simulate the two episodes. The data for the temperature fields used to force the model at the lower boundary region are taken from ECMWF analyses. The main results will be presented and compared to data derived from satellite measurements.

EVIDENCE FOR A SUBSTANTIAL ROLE FOR DILUTION IN NORTHERN MID-LATITUDE OZONE DEPLETION.

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Satellite measurements of ozone have shown a significant decline in ozone at mid-latitudes, and this has partially been explained by chemical models. Transport of air out the polar vortices has been shown to be modest, but after break-up of the vortex any ozone depleted air will eventually mix into mid-latitudes and cause a dilution there. For the Antarctic ozone hole this has been verified in model simulations. Here we show that the large ozone depletions in the Arctic vortex in spring 1993-97 lead to a dilution of northern mid-latitude ozone of about 2 % in 1993-94, which are comparable to TOMS trends in at 30-60 N May of 6 % from 1979-1994. In spring 1995-97 the dilution is about 3-4 %. These results indicate that dilution plays a substantial role in the mid-latitude ozone depletion in spring and summer, when the harmful effects of increases in UV radiation are largest.

ANALYSIS OF INTERANNUAL VARIATIONS IN TOTAL OZONE AND STRATOSPHERIC CIRCULATION

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Using the monthly mean TOMS (version 7) data the linear trends of total ozone are calculated for each month in 1979-1992 and analyzed with a special attention to the longitudinal structure. Together with the well known negative trends the positive total ozone trends were revealed in the distinct regions in particular westward from Greenland in January-February. The relations between interannual variations of total ozone and stratospheric angular momentum (NCEP data) were investigated by means of the calculations of the empirical orthogonal functions (EOF) and singular value decomposition (SVD) analysis. The results indicated strong link of total ozone anomalies with stratospheric circulation variations especially during winter/spring seasons, which confirm the findings for the evolution of zonally average fields in 1979-1991. It may mean that observed ozone trends can be mostly caused by interannual and decadal changes of stratospheric wave activity. The possibilities to distinguish the long-term natural and anthropogenic impacts on ozone layer are discussed.

QBO VARIABILITY OF TOTAL OZONE FOR ANTARCTIC SPRINGS AND ITS RELATION TO PLANETARY WAVES INTENSITY

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High resolution TOMS global data for each spring for 1979 - 1994 interval were used to study the correlation between the intensity of total ozone large-scale disturbances and ozone content over South pole during Antarctic springs with uzone hole"manifestation. The harmonic analysis procedure has revealed a strong QBO modulation of first harmonic amplitude with in phase of QBO oscillations of total spring ozone over South pole. The magnitudes of first harmonic reach of about 100 Dobson units for single years in contrast to the its smaller magnitudes at high latitudes of the Northen Hemisphere. The correlation coefficient between evolution of the first harmonic amplitude at 60 S in September and ozone content in October (after linear trend substraction) equals 0.7. The problem is to explain QBO effect in the planetary waves intensity.

THE 1998 ARCTIC OZONE DEPLETION QUANTIFIED FROM THREE-DIMENSIONAL MODEL SIMULATIONS

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Three-dimensional simulations of total ozone are reported for the 1997-98 Arctic winter. We used the REPROBUS chemistry-transport model which calculates the densities of 55 species or families of stratospheric interest, by means of a comprehensive photochemical package and a detailed description of heterogeneous reactions on liquid and solid particles. The comparison between the chemically integrated ozone and a passive tracer initialized like ozone allows to discriminate chemical changes from variations due to dynamical processes. This method is used to quantify the ozone chemical loss during the 1997-98 winter. Comparisons with ground-based and satellite observations are also presented.

NO_2 BALLOON-BORNE MEASUREMENTS DURING THE ILAS VALIDATION CAMPAIGN

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Measurements of NO_2 were performed on February 26, 1997 by the balloon-borne instruments LPMA and AMON before sunset, at sunset and at midnight, during the ILAS validation campaign at Kiruna (North Sweden). Vertical profiles have been obtained at very close location inside the polar vortex. These profiles will be compared to ILAS measurements of NO_2 performed also at the same date.
The data allows to study the diurnal variation of NO_2. The measurements will be compared to outputs of modelling works (box model and CTM 3-D model), taking into account ozone, chlorine and aerosol measurements also performed by the instruments. In particular, the existence of NO_2 below 23 km inside the aerosol layer, where modelling works predict zero value of NO_2 mixing ratio, will be discussed.

LIDAR OBSERVATIONS OF LEEWAVE INDUCED PSCS ABOVE ESRANGE IN NORTHERN SWEDEN

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For a quantitative understanding of Arctic ozone depletion the number, the timing, the duration, and the altitude of PSC events is a very important factor. According to the temperature analysis from the ECMWF in winter 1996/97 temperatures fell below PSC type I formation temperatures for only a few days in January 1997 and never reached PSC II formation temperatures above northern Scandinavia. In contrast our new backscatter lidar (light detection and ranging) on the Esrange (68°N) near Kiruna, Sweden, detected PSCs even on days when regional ECMWF temperatures were too high for any PSC formation. All types of PSCs were observed in this winter: very weak but depolarizing PSCs of type 1a with a backscatter ratio of 1.1 in parallel and 2 in perpendicular polarization, non depolarizing PSCs of type 1b with backscatter ratios of 3 to 5, as well as very strongly depolarizing PSCs of type 2 with backscatter ratios of up to 120 in parallel and 1600 in cross polarization. PSCs formed on 17 days over the lidar, most of them in January, a few in February, and one in March 1997. The altitudes of the PSCs ranged from 18 to 29 km. All of the "warm air" PSCs occurred when the windfield in the troposphere excited leewaves at the Scandinavian mountains which could propagate up to the stratosphere and lower atmospheric temperatures on a regional scale.

SIMULATION OF THE ANNUAL CYCLE OF TOTAL OZONE OVER NORTHERN HIGH LATITUDES AND COMPARISON WITH TOMS DATA

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The total ozone distribution in the polar area is a very informative indicator of the performance of a 3-D photochemical-transport model because it reflects the ability of the model to treat both dynamics and photochemistry in the atmosphere. On the other hand, the observations by TOMS provide a dataset that can be used for detailed validation of the simulated data. Accordingly, to estimate how successfully the total ozone distribution can be simulated, a numerical experiment with the 3-D UIUC Atmospheric Chemical Transport model has been carried out for 1993. In this simulation the distributions of trace gases are calculated with the model driven by circulation fields acquired from the UKMO dataset for 1993. A 3-year-long steady-state model run has been performed and the distribution of total ozone is compared with daily TOMS data for 1993. The comparison of the simulated and observed total ozone fields shows that the locations of the areas with high and low total ozone are simulated rather well. This means that the treatments of the chemistry and transport in the model are correct, and that the UKMO winds are very close to the true meteorological fields in 1993. The magnitude of the simulated total ozone field is slightly different from the observations and further improvement of the model is necessary to describe more accurately the destruction of ozone in the troposphere.

TRANSPORT RELATED O_3 VARIATIONS DURING THE AIRBORNE POLAR EXPERIMENT

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Reverse Domain Filling Trajectories (RDFT) analyses have been performed at the University of L'Aquila during the APE campaign to follow the vortex boundary movements and to obtain high resolution tracer fields used to examine the structure of the filaments eroded from the polar vortex edge. Focusing on the flights of 23/12/96, when the M55 Geophysika flew out of the vortex and across large filaments of inner-vortex and mid-latitude air, and 29/12/96 and 31/12/96, when a major intrusion of low latitude air into the vortex occurred, filament morphologies has been simulated and compared with O_3 data from the ECOC instrument onboard the M55. Similar filament morphologies can be found in tracers fields simulated for the same cases with SLIMCAT Chemistry and Transport Model (CTM) operating at the University of Cambridge. Coupled run and intercomparisons between RDFT and CTM calculation has been performed to understand our ability in reproduce the filament characteristics. Origin and characteristics of the global patterns responsible for the observed O_3 variations and reconstructed filament morphologies will be discussed.

TROPOSPHERIC OZONE RECORDING IN HIGH LATITUDES

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Surface ozone variations were measured at Svalbard (78 N) in August 1995 by Russian chemiluminescent ozone analyser AM-01. The surface ozone measurements were supported by ozone total content measurements with help of Russian M-124 filter ozonometer and were compared with some meteorological parameters. It was shown that the usual mean surface ozone concentration is equal to about 30 ppb and does not demostrate any diurnal course. Rapid surface ozone depletions up to 80% with duration from ten minutes to some hours and one intense enhancement of 120% value lasting about ten hours were discovered. A physical interpretation of such variations in terms of local topographically induced wind system which brings high bromine concentrations from surface sea water was suggested.

ROLE OF THE 11-YEAR SOLAR CYCLE IN A FORMATION OF THE WINTER VARIATIONS OF THE OZONE OVER NORTHERN EUROPE.

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On the basis of the monthly mean total ozone data for nine stations of Northen Europe for the period of 1957-1995 simple regression analysis of the connection between wintertime interannual variations of the ozone and the sunspot numbers is conducted. For the investigation the ozone data have been grouped according to the phases of the QBO. Simple regression analysis shows that the positive (negative) connection between the ozone and the solar activity is observed during the westerly (W) (easterly (E)) QBO phases. Results show that the influence of the 11-year solar cycle makes 1,1%, 7,4%, 35,2%, 35,6% of interannual variability of the total ozone over the region in months from December to March for the W QBO phase. For the E QBO phase this influence makes respectively 1,7%, 2,4%, 36,0% and 8,7% of the ozone variability. For the explanation of the obtained results simple regression analysis between the stratospheric indexes (30 hPa) over the region and the sunspot numbers is conducted. Regression model shows the similar dependencies as at the analysis of the Solar-Ozone relationship. As regression models applied for the ozone and for the indexes of stratospheric circulation over the region demonstrate similar results then it may be supposed that the Solar-Polar Ozone relationship is executed through the Solar-Stratospheric Dynamics relationship.

ON THE JOINT SOLAR/QBO EFFECT ON THE OZONE OVER NORTHERN EUROPE IN WINTERTIME.

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Using the monthly mean data of total ozone in months from December to March for the period 1957-1995 for Northen Europe stations the joint Solar/QBO effect on ozone variations is investigated. Correlation analysis conducted on condition that the data were divided according to the westerly (W) and easterly (E) QBO phases shows positive (negative) correlation between the ozone and the solar activity during the W (E) QBO phases. The highest correlations are obtained for February ($r = 0,63$ and $r = -0,59$ for the W and E QBO phases). To examine these statistical results all the ozone anomalies that exceed the standard deviation for a given month have been compared with solar activity. The comparison shows that almost all the ozone anomalies in February are in accordance with abovementioned statistical dependency. A correlation analysis conducted for the investigation of the connection between the stratospheric dynamics indices over the region and the sunspot numbers demonstrates similar results to ones for the Solar - Ozone relationship but in reverse ratio (for February $r = -0,65$ and $r = 0,59$ for the W and E phases). As close connection between the indices and ozone variations ($r = -0,70$ for February) is revealed then it may be concluded that the Solar - QBO - Polar Ozone relationship is executed through the stratospheric circulation.

THE THERMAL STRUCTURE OF THE ANTARCTIC LOWER STRATOSPHERE BEFORE AND AFTER THE DETECTING OF THE OZONE HOLE

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First results of an investigation upon the development of the thermal structure of the lower stratosphere of the southern polar region in dependence of ozone are shown.
From the reanalysis datasets of NCAR/NCEP and ECMWF meteorological parameters are taken. Ozone data are used from TOMS and additionally ozonesonde data are evaluated. Temperatures and zonal wind in different stratospheric pressure levels are applied to establish the variation of the thermal structure and the transition of the winter to the summer circulation during the period of 1979 to 1993. Undisturbed „pre-ozone hole" years are compared with. The relation of ozone concentrations and temperatures in a temporal and a spacial kind and in consideration of the polar circulation is described and quantified.
Periodical fluctuations like solar cycle and QBO and single events like volcanic eruptions are considered.

STRATOSPHERIC ARCTIC WINTER PROFILES OF N_2O, CH_4, H_2O AND HDO, MEASURED BY MIPAS-B

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Vertical profiles of CH_4 and H_2O inside the arctic vortex were retrieved from nighttime infrared limb emission spectra measured by the Michelson Interferometer for Passive Atmospheric Sounding, Balloonborne version (MIPAS-B) instrument from Kiruna (Sweden, 68°N) on February 11, 1995 and March 24, 1997. The results of the February flight show a peak mixing ratio of nearly 7.0 ppmv H_2O at 17.1 hPa and a minimum of 3.6 ppmv H_2O at 137.5 hPa corresponding to 28 km and 13.2 km altitude. The analysis of the March flight shows a similar profile, but the vertical gradient is less pronounced. The total hydrogen budget of the stratosphere has been examined by evaluating the quantity $[H] = [H_2O] + 2\ [CH_4]$. A mean mixing ratio of [H] is calculated from the data revealing high values of around 7.25 ppmv for both flights. A compact correlation between CH_4 and N_2O was also deduced from the measurements. From the spectra of the February flight a vertical mixing ratio profile of HDO has been inferred, too. The deuterium to hydrogen ratio (D/H) of water vapor shows a strong depletion in comparison to that of Standard Mean Ocean Water (SMOW) particulary in the lower stratosphere. These depletion is a hint of a possible dehydration by PSC particles which occurs at a lower altitude than that of the denitrification measured on the same flight.

STRATOSPHERIC CHEMISTRY MODELLING: RESULTS OF A BOX MODEL AND A THREE-DIMENSIONAL CHEMISTRY TRANSPORT MODEL

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A stratospheric chemistry routine is developed and tested in a box model. The routine contains 43 species and 154 reactions, of which 29 photolysis reactions and 18 heterogeneous reactions on ice, NAT and liquid aerosol. As a numerical solver Euler Backward Iterative is used, taking a 40 minute timestep and 10 iterations. This new routine is examined with the help of idealized trajectories and a previously validated box model.
The chemistry routine is then implemented in a three-dimensional chemistry transport model, TM3. This model is forced by analyzed ECMWF wind and temperature fields. Results are compared with ozone sonde measurements and other balloon- borne and aircraft measurements, which were carried out in the SESAME winter, 1994-'95.

ABOUT THE CHANGES OF THE OZONE CONTENT OVER THE EAST ANTARCTIDA

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It has been considered the ozone changes on the base of ozonesonding obtaining data from the German balloon station G. Foster (70° 46' South , 11°50' East) for the period 1985-1991. These data are compared with the derived results from the Russian station Mirnii (66° 33' South , 93 °01' East).The main statistical characteristics of vertical profiles are presented .A special attention is paid to the Spring reduction of the ozone content during October-November.After the detailed analysis it is concluded that the chemical ozone loss in spring is significantly controlled by dynamical processes. This dynamical control is understood as a natural impact on the polar ozone depletion As it can be shown the strong circumpolar vortex circulation weakens the advection of air towards polar latitudes.

ST15 Atmospheric ozone (joint with OA)

Convener: Hirschberg, M.-M.

03 Changes in UV-B radiation

Convener: Krüger, B.C.

CAN INCREASED UV RADIATION CAUSE SURFACE OZONE EPISODES?

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A case study is presented which shows a remarkable coincidence of very low total ozone and high near-surface ozone concentrations (>60 ppb) in Switzerland in February 1993, lasting one week. The meteorological situation changed little during this period, and a high-pressure system provided good conditions for photochemistry on a regional scale. The reason for the low total ozone probably is anomalous stratospheric circulation and a chemical effect of Pinatubo aerosols.

Total ozone contains information about the tropospheric circulation which is an important influence on surface ozone concentrations in winter. However, it can be shown that during the episode surface ozone concentrations depended largely on photochemical ozone destruction (at the high-alpine site Jungfraujoch, 3580 m asl, with ~0.05 ppb NO_x) or production (at the elevated site Chaumont, 1140 m asl, with ~4 ppb NO_x) while transport was weak. The mean diurnal ozone cycles show an increase of ozone concentration at Chaumont and a decrease at Jungfraujoch during the afternoon hours. The amplitude at Chaumont is 8 ppb which is comparable to summer conditions. Such a strong photochemical activity is not expected in late winter. As ozone production at Chaumont at that time is limited by solar radiation rather than by precursor concentrations, the strong photochemical activity is probably due to enhanced radiation. This can be caused by two effects: the backscattering at a fog layer and the increased UV radiation due to low total ozone. The latter influence can roughly be estimated. Compared to normal conditions, the 30% negative deviation of total ozone observed (243 DU) leads to an increase of ozone photolysis of up to 80%. It is suggested that in this extraordinary case increased UV radiation lead to increased photochemical activity and caused an early surface ozone episode.

UV-B RADIATION AND OZONE BEHAVIOUR AT ROME STATION IN THE RECENT SIX YEARS

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It is well known that the total ozone depletion is the main factor influencing the changes in solar UV irradiance at the earth's surface. At the midlatitudes an ozone decline associated to UV-B increase was observed (Kerr and McElroy, 1993; Zerefos et al., 1995; Seckmeyer and McKenzie, 1992).

The solar UV-B (290-325nm) irradiance and daily total ozone data have been collected by Brewer spectrophotometry at Rome station since 1992. The below normal ozone episodes during the period 1992-1998 are derived from the comparison between actual data and ozone long time series. The UV-B daily irradiances are analysed taking in account various atmospheric influences, such as cloud cover, turbidity and ozone content. Fluctuations, trends and anomalies in UV-B series are described and considered as a function of various temporal scales and dominating factors.

THE DEPENDENCE OF THE SOLAR UV-B RADIATION ON TOTAL OZONE AND SOLAR ZENITH ANGLE

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The contribution reports on an analysis of solar UV-B radiation measurements made by RB-Biometers simultaneously in two locations: Hradec Králové (285 m a.s.l.) and Milešovka (836 m a.s.l.). The analysis of the series of 10-minute sums obtained during one year (96/8 - 97/7) is focused on (i) comparison of the UV-B radiation regime in the two locations, and (ii) determining the dependence of UV-B radiation on total ozone and solar zenith angle. Using the regression relations determined in the latter step, the changes in local UV-B radiation climatology due to changes in total ozone will be deduced.

The analysis is made within the frame of a joint grant project of the Czech Hydrometeorological Institute and Institute of Atmospheric Physics. The project aims at: (i) monitoring of biologically active UV-B solar radiation, (ii) assessment of relations between total ozone and UV-B radiation, and (iii) creation of the information system for operative reports on UV-B levels and exposure times recommended for population.

OZONE AND QBO VARIATION IN THE EQUATOR ATMOSPHERE

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Quasibiennial oscillations (*QBO*) of the ozone concentration and temperature, which occure in phase with the quasibiennial variations of the solar ultraviolet are discussed. Physical mechanism for ozone influence on *QBO* of equatorial east-west stratospheric zonal wind are proposed. These winds are transfered to the troposheric heights with turbulent diffusion and can influence on the dynamic of atmosphere. Thus the solar activity controls the origin of atmospheric circulation with *QBO* period. This can explain the initiation of some planetary atmospheric events in particular *ENSO*, which varies with double-*QBO* period.

THE INFLUENCE OF RADIATION ON TROPOSPHERIC CHEMISTRY.

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The effect of changes in the solar radiation on the chemistry of the troposphere has been investigated for a wide range of concentrations of hydrocarbons and nitrogen oxides, which covers many possible cases from clean to strongly polluted areas. Such changes of radiation might be caused by a reduction of the stratospheric ozone layer or by the variability of the atmospheric aerosol content. Model calculations were performed, which show, that the concentrations of atmospheric oxidants like ozone, hydrogen peroxide, nitric acid or PAN increase with stronger ultraviolet radiation in most cases.

LONG-TERM CHANGES OF THE SURFACE UV RADIANCE AT BELSK, POLAND, 1966-1996

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The measurements of the daily UV dose by means of the Brewer spectrophotometer (1993-1996) and the Robertson Berger meter (1976-1992) are combined to form the time series of the monthly means of the UV daily dose (erythemally weighted) for the 1976-1996 period. The UV time series for the 1966-1976 period is reconstructed based on the statistical model using the measured values of total ozone and global sun radiation (used as a proxy for the cloud and aerosols effects on the UV) as the UV predictors. The reconstructed UV data for the 1966-1976 period shows a downward tendency. It seems that the global radiation changes influence mainly the UV level in that period. An increase in the UV dose of about 6% per decade (statistically significant) is forced by the total ozone depletion (about 4% per decade) over Belsk in the 1976-1996 period. The long-term variations of the UV dose based on the model running for the 1976-1996 period are almost the same as those from the measurements. This suggests that the long-term changes in other the UV forcing factors (e.g. ozone profile, optical characteristics of the clouds and aerosols) do not affects the UV trend significantly.

VOLKANIC ERUPTIONS IMPACT ON ULTRA VIOLET RADIATION REGIM

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The response results of all UV flux radiation components (direct, actinic, upward, downward) in polar, middle and tropical latitudes on volcanic aerosols presense in the atmosphere after Penatubo and Al Chichon eruptions are presented in the report. For influence estimation of aerosols distribution fine structure the new model of UV radiation fluxes counting was developed. The model uses Edington delta method for approximate radiation transfer equation solution and high precise matheatical apparatus for providing high altitude (to 1 meter) and wave length (to 0.01 nm) resolutions and automatical fine structure searching. This model takes into account Rayleight and many-times scattering, ozne, aerosol and cloudiness delution and layer surface reflection.

In the report the dependance of altitude structure and stectral distribution of our flux components transformation on volcanic aerosol distribution in middle and polar latitudes were analysed. The most interesting dependances are observed in the upward radiation spectral behaviour normed on the undisturbed radiation level. Upward flux responce on ozone change after eruption appear in local spectral maximum situated in the spectral areas 303 nm, 25% (tropics), 312 nm , 13% (middle) and 320 nm, 12% (polar) for Penatubo eruption.

USING SATELLITE MEASUREMENTS FROM GOME FOR THE ESTIMATION OF THE UV IRRADIANCE AT THE EARTH'S SURFACE

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We present some preliminary results of global UV fields estimation at the Earth's surface computed using data from the GOME instrument. A first simple model is used to test the best strategy for implementing the cloud modelling. It relies heavily on the cloud coverage estimation from GOME (ICFA and PMD measurements). A second, more accurate model will include the best approach and will be derived from the algorithm developed for the TOMS instrument by NASA/GSFC.

Maximum UV-Levels Measured on Alpine Radiation Stations

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In the Swiss Alps UV-radiation is continuously measured at the radiation stations Davos (1610 m a.s.l.), Weissfluhjoch (2540 m a.s.l.) and Jungfraujoch (3580 m a.s.l.). UV-measurements are based on erythemally weighted UV-Biometers which predominately measure UV-B radiation, and broadband filter instruments measuring the UV-A part of the spectrum. Three UV-Biometers measure direct, diffuse and global UV-B components and are periodically exchanged and calibrated. At Davos and Weissfluhjoch an instrument with a 2 pi full view angle is mounted on a solar tracker to measure maximum UV-B radiation normal to the sun. Ground reflected components are measured at the station Weissfluhjoch. Analysis of measurements from the last two years focus on maximum UV levels for the different components. Clear sky maximum levels are compared to broken cloud cases for different integration times. 2 pi full view angle measurements for different solar zenith angles are compared with respect to the orientation of the instruments, for snow covered (winter) and uncovered (summer) surfaces.

IMPACT OF OZONE PROFILE ON THE SURFACE UV RADIATION: ANALYSES OF THE UMKEHR AND UV DATA TAKEN AT BELSK, POLAND, 1976-1996

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The trend analysis of the monthly means of surface UV daily doses (erythemally weighted) reveals an increase of the UV level at Belsk, Poland, of about 6% $\pm$ 1.3% per decade since January 1976. An impact of the ozone profile changes on the UV irradiances at the ground level is studied based on the Umkehr data. Temporal variations of the ratio of the ozone content in Umkehr layers 1-4 (about 0-23km) and that in Umkehr layers 5-10 (about 23-48km) is used as an index of the ozone profile changes over Belsk. The 1976-1996 trend in the ratio is $-5.2\% \pm 1.4\%$ per decade suggesting the stronger ozone depletion in the lower stratosphere than that in the upper stratosphere. Both the statistical model (regression of the UV monthly dose on monthly means of total ozone, global sun radiation, and the above mentioned ratio) and the radiative transfer model (LOWTRAN 7) show that the ozone profile changes over Belsk influence only slightly the long-term variations of the surface UV radiation there.

SNOW AND CLOUDS EFFECTS ON THE ERYTHEMAL UV RADIATION. ANALYSIS OF SWISS MEASUREMENTS AND MODELIZATION

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Direct, diffuse and global erythemal UV radiation are continuously measured at Davos (1610 m a.s.l) and Payerne (490 m a.s.l.) by using UV-Biometers (Solar Light Co, model 501). This data set and a radiative transfer model (two-stream TUV) are used to estimate the effect of a snow covered surface as well as of a cloud cover on the erythemal UV radiation.

In the presented analysis, the data at Davos from May 95 to April 96 were normalized to a constant total ozone amount (300 DU) and constant distance sun-earth (1AU) to avoid any influence of these factors.

The clear sky radiation in case of a snow covered surface (winter) is found to be 20-30% higher than without snow (summer), with an enhancement increasing with increasing zenith angle (40-60°). The snow effect for winter aerosol conditions is estimated by using the radiative transfer model. The attenuation due to a cloud cover is estimated for snow covered surfaces and snow free surfaces. The average attenuation is found to be 60-64% for a snow free surface, and 50-56% for a snow covered surface. The radiative transfer model is used to get an estimation of the optical depth of the cloud cover.

RELATIONSHIPS BETWEEN THE ATTENUATION OF SURFACE UV IRRADIANCE AND THE RADIATIVE PROPERTIES OF THE SATELLITE-DERIVED CLOUD FIELD.

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Cloud observations from the International Satellite Cloud Climatology (ISCCP) dataset are combined with spectral and broadband surface UV irradiance measurements to study the effect of varying cloud radiative properties on solar radiation received at the ground. From the satellite observations, cloud cover, cloud optical thickness, and cloud top pressure are retrieved and are used to derive radiometric definitions of cloud type. The global irradiance data are then correlated with the radiative properties of the cloud field, and the relationships between cloud type and the attenuation of surface UV irradiance are examined. In parallel, the satellite data are compared with conventional cloud observations from local meteorological stations to investigate the differences of the two methods and their suitability for use in solar radiation studies. The UV irradiance data used in this study are obtained from a Brewer spectroradiometer operating at Thessaloniki and from the network of broadband detectors of the University of Thessaloniki, covering a wide area over Greece. The analysis is done for two months, one in the summer and one in the winter season.

ST15 Atmospheric ozone (co-sponsored by OA)

Convener: Hirschberg, M.-M.

04 Tropospheric ozone with emphasis on the Mediterranean region

Convener: Varotsos, C.

Free tropospheric ozone variations at Athens, Greece

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Many uncertainties still exists concerning the stratosphere-troposphere exchange (STE) of ozone. STE mainly occurs during the mid-latitude tropopause foldings as well as during cut-off low events. In the present study the stratosphere-troposphere ozone exchange over Athens, Greece, during the period from 1991 to 1997 is examined in relation to the presence of a cut-off low pressure system in the upper troposphere or a possible tropopause folding, when the station is close to the flank of an upper level trough. For this examination, the ozonesounding data during the above mentioned period are used along with the corresponding prevailing meteorological situation.

Tropospheric ozone contribution to surface warming at Athens, Greece

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The atmospheric greenhouse effect and its contribution to global climate change are of great importance the last decades. The tropospheric ozone as a greenhouse gas has a significant role to the overall greenhouse effect. In this study an estimation of the greenhouse effect over Athens, Greece, as deduced from satellite data up to 1992 and the contribution of tropospheric ozone is attempted. Additionally, the trend of tropospheric ozone is examined for the time period 1992-1997 in order to assess its contribution to the atmospheric greenhouse effect up to 1997.

SHORT AND LONG TERM VARIABILITY OF THE VERTICAL OZONE PROFILE IN THE MEDITERRANEAN REGION

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The impact of Mediterranean emissions on free tropospheric ozone will be discussed using, on one hand, a study of a long term time serie of ozone profiles measured at the Observatoire de Haute Provence (OHP) in Southern France, and on the other hand, a vertical cross section of ozone measured in September 1996 along the East coast of Greece. The OHP time serie shows no positive trend of the yearly ozone mean during the 80's, but a significant change of the seasonal variation consistent with increased photochemical production in the summer. The importance of photochemistry is confirmed by the absence of a significant change in the strength of stratospheric ozone transport to the troposphere. The discussion of this climatological analysis will include a presentation of the data validation procedure which is mandatory for such a study. In order to illustrate the importance of Mediterranean emissions on ozone in the free troposphere, an example of an ozone rich layer transported from Spain to Greece will be discussed using airborne lidar measurements and meteorological analysis.

STUDY OF THE OZONE SINK ONTO ULTRAFINE AEROSOL PARTICLES.

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Since both the ozone and aerosols are very important atmospheric contaminating components, and taking into account that ozone can promote the formation of aerosol particles and, on the other hand, aerosol particles can cause ozone destruction the investigation of the interrelation between these components very important for the interpretation of their transformation in the atmosphere. For the most part, information on this problem is based on the data obtained during experiments carried out under laboratory conditions. In this paper we try to estimate the ozone sink based on the data obtained during measurements of ozone and aerosol concentrations in the real atmosphere. In 1993 in the framework of TOR project (EUROTRAC programme) the station for ozone monitoring (TOR-station) has been constructed in the Institute of Atmospheric Optics (Tomsk). All measurements of ozone concentration are accompanied with measurements of all standard meteorological quantities. In 1996 a diffusion battery was include to the measurement complex of this station. It allowed us to measure a number concentration of aerosol particles in the 3 to 200 nm diameter range. As a result of these measurements we have obtained continuous series of ozone concentration and aerosol size distribution in the surface boundary atmospheric layer near Tomsk. The rate of the ozone sink onto ultrafine aerosol particles is estimated.

STUDYING PERIODS OF HIGH OZONE CONCENTRATIONS IN THE MEDITERRANEAN REGION DURING A 7-YEAR PERIOD

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Tropospheric ozone is one of the most harmful pollutants causing damages to human health and plants. According to the EU regulatives the population should be informed when the hourly values of the ozone concentrations are greater than 90 ppb. Moreover, warning must be sent whenever these values exceed 180 ppb. The damaging effects on vegetation depend on the magnitude of the cumulative ozone exposure. Therefore both the damaging effects on human health and on plants must be carefully studied. The long-range transport model, the Danish Eulerian Model (DEM), has been used in this work. Meteorological data from 7 consecutive years, from 1989 to 1995, have been used in different scenarios for varying emissions of NOx and VOC. Advanced visualization techniques are used to interpret this large amount of digital data. The model results have been compared with measurements taken at stations located in the Mediterranean region. Furthermore, DEM has been coupled to the effect model (TreGro) in order to determine the impact on trees. It is shown that the information and warning threshold for the EU population, and the cumulative ozone exposures for plants are highly exceeded in most of Europe and especially in the Mediterranean region.

PECULIARITIES OF THE OZONE FORMATION IN THE BOUNDARY LAYER OF THE ATMOSPHERE OVER SOME REGIONS OF THE FORMER USSR

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Since 1988 till 1991 the Institute of Atmospheric Optics has carried out regular airborne sounding of ozone over the whole territory of the Former USSR in the lower troposphere up to 8 km altitude. The data processing showed that the most significant peculiarities of ozone generation occur in the boundary layer of the atmosphere. There is only small latitudinal gradient above the boundary layer of the atmosphere. These peculiarities lies in the following facts. Altitude and intensity of ozone concentration maximum depends on properties of underlying surface. The highest altitude and intensity were recorded over regions covered by forests. There is longitudinal gradient of ozone concentration in the boundary layer of the atmosphere which is oriented from eastern to western regions. There is a lower surface inversion which results in two-layer ozone generation. In the boundary layer of big industrial centres. emissions from enterprises influence the strength of the ozone concentration maximum. They reduce its level. The ozone concentration decreases in the presence of the atmospheric fronts. It is regenerated during next 1 or 2 days. This study was financed by Russian Foundation of Basic Studies (grant № 96-05-64332).

EARLY SPRING OZONE EPISODES: OCCURRENCE AND CASE STUDY

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In Switzerland, near-surface ozone concentrations exceed 60 ppb for the first time of the year often already in February. Elevated rural sites (Chaumont, 1140 m asl, Rigi, 1030 m asl) first show these ozone peaks. They are sited 600-700 m above the Swiss Plateau, which can form at that time a pool of cold, NO_x-rich air. Later, in April, rural lowland stations also show high peaks, while elevated sites already have monthly means of up to 50 ppb. Ozone peaks above 60 ppb in early spring (Feb-Apr, 1992-1997) typically occur in episodes of several days with high solar radiation and air temperature maxima above 6 °C. The corresponding NO_x daytime mean at elevated sites is 5-10 ppb, which is close to the optimum concentration for ozone production. While in the lowland, NO_x concentrations can be too high for efficient ozone formation, the key limitation at elevated sites in early spring is the solar radiation.
On fair weather days in early spring, the daily cycle of ozone concentration at elevated sites shows a clear maximum in mid-afternoon. Thermotopographic transport of emissions from lowland sources influences the precursor concentrations, however, ozone is probably mainly produced above the lowland due to chemical limitations. More rarely, ozone peaks occur after sunset or in the early morning, indicating vertical or horizontal transport, possibly in reservoir layers. In all, early spring ozone peaks are caused by *in-situ* photochemical ozone formation rather than transport.
A case study of 16-21 March 1990 shows a large scale ozone episode associated with a slowly eastward moving high-pressure system and high temperatures in Central Europe. Data from sites aligned west-east at different elevations in Switzerland, Tyrol, eastern Austria, and central Hungary show an increasing (from 70 to 100 ppb) while slowly eastward moving ozone peak. It is suggested that ozone was formed in a large area travelling 1000 km within 3-4 days within the anticyclone.
The study shows that long-lasting anticyclonic conditions, which were a dominant feature in spring 1996 and 1997 in Central Europe, can promote considerable photochemical ozone formation on a regional to large scale already in early spring.

ON THE ROLE OF AIR POLLUTION ON THE SOLAR RADIATION REACHING THE GROUND

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Solar Ultraviolet Rariation (UV-A and UV-B) measurements at Athens, Greece (380N, 240E) are examined with respect to the influence of photochemical pollution. Furthermore results of UV irradiance as deduced from a simple parametric model are compared with actual field measurements. The results show that the hypothesis of UV-B depletion is significant at an almost 95% confidence level. It is also shown that photochemical pollution effect on UV-B is as three times larger as on UV-A irradiance levels.

TROPOSPHERIC OZONE RELATED CHANGES IN BIOLOGICALLY ACTIVE ULTRAVIOLET RADIATION

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The influence of temporal surface ozone variations on the solar ultraviolet radiation reaching the ground is investigated. Comparison between historical (1900-1940) and recent (1987-1997) surface ozone data, monitored at Athens is discussed, in order to detect the plaussible variations in Ultraviolet Radiation reaching the ground. Furthermore the confirmation of the hypothesis that increased levels of atmospheric pollution may act as filter to the transfer of solar ultraviolet radiation to the surface is attempted.

APPLICATION OF CHEMILUMINESCENT OZONE ANALYZERS UNDER GEOPHYSICAL AND LABORATORY EXPERIMENTS

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It is known that the chemiluminescence observed during the oxidation of organic substances in heterogeneous conditions is used as a basis for building inexpensive, yet rather sensitive, contact-type gas analyzers for ozone. Having light weight, long life time, high response time and sensitivity such analyzers are used for solving tasks of ozone atmospheric monitoring and laboratory research. However by the moment the features of chemiluminescent sensors applications for the ozone concentration measurement under extending dynamic range conditions as well as interference of measured concentration range and life time duration, sensitivity stability in time of chemiluminescent sensor were not studied enough. This paper investigates some features of heterogeneous chemiluminescent ozone sensors operation, limits for the sensors application and measurement procedures based on chemiluminescent sensors and system analysis of sensors metrological specifications. Requi rements for the design of chemiluminescent ozone analyzers used as a part of automatic atmosphere pollutant control stations and analytical laboratories have been formed.

On the seasonal variation of photo-oxidants at the greater Athens area

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On the present study, the seasonal variation of photo-oxidants O3 and Ox (Ox=O3+NO2) is examined. Analysed data concern the period 1990-1996 and cover the whole greater Athens basin. The seasonal analysis concerns Summer (May-August), Winter (November - February) and transition (March, April, September, October) periods. Analysed data have been devided into three categories (24-hour, daytime and night-time) and the major statistical parameters were examined (mean value, median, standard deviation). Parallel to the seasonal variations, plaussible correlation between surface ozone and Ox concetrations are discussed. Results show a pronounced decline on surface ozone concentrations during the last years.

GAS PHASE REACTION OF HYDROXYL RADICAL WITH THE NATURAL HYDROCARBON BORNYL ACETATE

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The gas phase reaction of bornyl acetate (bicyclo[2,2,1]-heptan-2-ol-1,7,7-trimethyl-acetate), VOC emitted by Mediterranean trees (orange and mandarin trees) with hydroxyl radical has been studied. The rate constant determined at 294 ± 2 K is $k = (13.9 \pm 2.2) \times 10^{-12}$ $cm^3.molecule^{-1}.s^{-1}$. The experimental rate constant has been compared with the rate constants calculated with the structure-activity relationship (SAR) and with the evolution trend of the acetate rate constants. 1,7,7-trimethyl-bicyclo[2.2.1]-heptan-2-one, 1,7,7-trimethyl-5-acetyloxy-bicyclo[2.2.1]-heptan-2-one and 1,7,7-trimethyl-6-acetyloxy-bicyclo[2.2.1]-heptan-2,3-dione were identified as degradation products. Their estimated formation yields were very low (< 1 %). The reaction of bornyl acetate with OH radical leads to organic aerosols. The fraction of the carbon initially present that is converted to aerosol, has been estimated to about 5%. 1,7,7-trimethyl-6-acetyloxy-bicyclo[2.2.1]-heptan-2,3-dione has been identified as aerosol product.

On the statistical analysis of tropospheric and stratospheric ozone content over Athens Greece

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This study reports observations of the total ozone content (TOC) made by Dobson spectrophotometer at Athens Greece (38N,24E) for the time period 1994-1997. We have also used the ozonesoundings performed regulary at Athens, the same time period in order to define by integration the total tropospheric ozone amount. The final purpose is to separetely study both the tropospheric and stratospheric total ozone content by means of Fourier analysis paying special attention to the TOC minimum at 1996.

A STATISTICAL MODEL FOR THE RELATIONSHIP OF OZONE AND ITS PRECURSORS AT ATHENS BASIN

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Concentrations of surface ozone and its precursors (Nox and hydrocarbons) at Athens Basin are correlated with the temperature at 850 hPa level. The expression of the relationship of ozone to its precursors via polynimial and multiplicative regression models is attempted. Results show that, according to the regression models, the correlation coefficient increases from 0.73 to 0.98

ON THE ORIGIN OF THE ELEVATED SURFACE OZONE CONCENTRATION IN SPAIN

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The objective of this work is to study the influence of three mechanisms in the high surface ozone concentration of the Spanish EMEP stations. These mechanisms are: Photochemical production from organic compounds and nitrogen oxides, exchange of air between the Planetary Boundary Layer and the free troposphere and the advection of ozone. To do this we have designed a new method that use multivariate analysis and the average ozone concentrations, NO_x concentrations, leght of the air mass trajectories reaching the stations and emissions of NO_x. Results suggest that high surface ozone concentrations are controled by photochemical production if the source is close to the station. If the distance from the source to the station rises, the influence of the NO_x emissions become more important.

GEOGRAPHYCAL SOURCES OF SURFACE OZONE IN SPAIN

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Geographycal sources of surface ozone in five Spanish EMEP stations are studied using the air mass trajectories that arrive at the stations together with the CPFs (Conditional Probability Functions). Results show that regions with strong NO_x emissions placed far away the stations are the main sources of ozone in Spain. So, the center of Europe and the middle Mediterranean area are the two main geographycal sources of surface ozone in Spain.

MONTHLY VARIATION OF THE SURFACE OZONE IN SPAIN

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This study summarized the analysis of the monthly ozone concentrations done in five Spanish EMEP stations. From of the five considered stations show the typical natural spring maximum. This maximum extends into summer in two of the stations. In one of the stations the maximun is reached in summer and it is due to the proximity of this station to strong nitrogen oxide emission areas.

DIURNAL VARIATIONS OF THE SURFACE OZONE IN SPAIN

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In this study we present the diurnal and monthly variations in the surface ozone concentrations of five Spanish remote stations belonging to the EMEP network. In one of the stations the diurnal cycle is dominated by the breeze wind flow regime reaching a peak in the morning. In two of the stations, a maximun in the afternoon is presented because of the turbulent mixing producing appreciable downward ozone flux. In the order two stations no maxima are produced. In one of them this result is due to the strong westerly winds that dominate the air flow and the low solar insolation. In the other station the reason are two phenomena: the mountain induced flow regime that produce high concentrations during the night and the photochemical production that results in high concentrations during the afternoon.

TRANSPORT OF OZONE AND ITS PRECURSORS FROM SOUTH EUROPE REGION AND ITS INFLUENCE ON OZONE LEVEL IN LITHUANIA

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According to separate authors surface ozone concentrations in rural areas of Europe have been increasing at a rate of 1 to 3% per year over the past two decades. Surface ozone data show an increase by 2.5% per year over 1982-1996 at the coastal rural station Preila, Lithuania. An increase of ozone maximum concentration by 1% per year during this period is observed. The ozone level increase in Lithuania is mainly determined by the transport of polluted air masses rather than by local pollution. The ozone and its precursors concentrations are analyzed during episodes when the air mass from south Europe reached the Lithuanian territory. The air mass transport from this region is registered when the eastern part of the southern cyclone moving via the Czech, Poland and the Baltic sea reaches the Lithuanian territory. The southern air mass transport is observed also in the front part of the cyclone that is moving over north Poland from the West Atlantic Ocean. More rarely the southern transport is determined by the settled western part of a powerful Siberian anticyclone. The investigated cases were grouped over cold and warm periods of the year. Air masses from south Europe during the warm period are mostly distinguished for high ozone (>70 ppb) and other species level. During the cold period ozone concentrations are usually under 50 ppb.

On the Ozone Content of the free troposphere over Athens Greece as derived by using in situ techniques

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Ozone Content of the free troposphere over Athens Greece during the winter-spring period is examined based on observations made by using the ozonesounding technique. This study covers the period 1991-1997 when intensive ozonesounding campaigns took place at Athens, Greece (38 N, 24 E). Variations of tropospheric ozone are correlated with the corresponding Total Ozone Content (TOC) ones during the same period. The impact of prevailed meteorological condition is discussed. Additionally integrated TOC values as derived from ozonesounding profiles, Dobson #118 spectrophotometer and TOMS/SBUV satellite born measurement are cross examined. Finally a first approach on the evaluation of satellite born SBUV data concerning the lower atmospheric ozone content is attempted.

TIME VARIABILITY OF GROUND OZONE CONTENT WITHIN DIFFERENT CLIMATE REGIONS OF THE EARTH

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The time variability of ground ozone content has as regular pseudoperiodical) so unregular character. The first type of variability is caused by sunearth connections as well atmosphere general circulation and wave motion. The statistic analysis of ozone experimental data has been carried out to determine different fluctuation periods from minute to season variations for various climate regions from polar to tropical latitudes. Daily, 48 hours and season variations are shown evidently.The variations with shorter periods depend on many factors including observation latitude, profile and type of ground surface. An interference of wave processes of different origins which is responsible for period duration changes is assumed to exist. A special attention was paid to the nature of fluctuations with periods from 5 to 7 minutes. The second type of variability is caused by aperiodic atmospheric processes in particular by discharging ozone destructing and ozone generating substances of different concentrations and flow rates into atmosphere. Sources of aerosols of different nature as well nitrogen oxides, organic substances have a special significance. Experimental data on ozone concentrations in dependence of aerosols and nitrogen oxides are considered.

SURFACE OZONE CONCENTRATIONS AT RURAL LOCATIONS IN POLAND IN 1996

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The results of surface ozone measurements performed at five stations are presented. Measurement stations are lokalized out of direct influence of pollution sources (except station in Warsaw). The results of ozone measurements give us the information how high are ozone concentrations and their daily and seasonal variations in various regions of Poland, regarded as having clean or almost clean air. Frequent epizodes of high ozone concentration were observed at all stations in the first half of 1996. First of them occured in February, when daily means at rural stations were above 100 $\mu g/m^3$. Similar episodes occured in March, April and June. Analysis of episodes indicate that they were caused (except the last one) by dynamical transport of air from the upper layers of the atmosphere. Analysis of ozone concentrations dependence on meteorological parameters and other gaseous pollutants (NO_2, SO_2, CO) for Belsk station indicates that dynamical processes (vertical and horizontal airmass transport) have substantial influence on changes of surface ozone concentrations.

FIVE-YEAR RECORD OF OZONE AT MT. BROCKEN (GERMANY) - IMPLICATIONS FOR CHANGING HETEROGENEOUS CHEMISTRY

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Theoretical studies using models with coupled gas and liquid phase chemistry suggested that not only the net formation of ozone could be reduced in clouds but also heterogeneous destruction could be possible. Several possible pathways of ozone sinks in clouds we discussed recently concerning first experimental findings of ozone depletion at Mt. Brocken [Acker et al., 1995]. Since 1992 we record the ozone concentration beside several other air and cloud chemical and physical parameters at Mt. Brocken. Now we present the changing seasonal amplitude of ozone (increasing winter ozone concentration whereas the summer ozone remains nearly constant) as an indication for a loss of winter time ozone destruction in clouds. We found that between the amplitude (summer/winter ratio) and the station elevation above sea level a strong correlation exists. However, the corresponding ratio for Mt. Brocken exceeded the expected one (2.3) nearly by a factor of two in 1992. Till 1996 we observed a decreasing amplitude, now in agreement with the „normal" correlation. Considering parallel changing cloud chemistry parameters (e.g. acidity) we present the hypothesis of loosing ozone removal capacity in the winter season. Moreover, we would like to stimulate the discussion on the importance of heterogeneous sink processes for the mesoscale oxidant budget.

K. Acker, W. Wieprecht, D. Möller, G. Mauersberger, S. Naumann and A. Oestreich (1995) Naturwiss. 82, 86-89

CHARACTERIZATION OF AEROSOL PROPERTIES AND DIRECT RADIATIVE FORCING AT AN ANTHROPOGENICALLY PERTURBED CONTINENTAL SITE

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Ambient aerosol particles affect the radiation balance of the Earth directly or indirectly. This can have an effect on climate but also on tropospheric ozone chemistry and vertical distribution as more radiation can be available above than below the aerosol layer. In addition, secondary particulate pollutants are formed by the same precursors as ozone. Therefore, ozone chemistry and aerosol particle chemistry and optical properties are interrelated. Measurements of optical, chemical and physical properties of ambient aerosol particles were obtained during 1995 at a sampling station, at Bondville (N 40o 03' 12" N, 88o 22' 19" W), Illinois, USA, a site representative of a continental anthropogenically perturbed environment. The inorganic water soluble aerosol comprised half of the total gravimetric mass and it was dominated by ammonium and sulfate ions. Organic and elemental carbon constituted the rest of the gravimetric mass. The upscatter fraction and the hygroscopic growth factor as functions of wavelength of light were quantified from the measurements. The quantified parameters were used in a box model to estimate the difference in the clear-sky shortwave flux at the top of the atmosphere caused by the aerosol particles in the region.

NUMERICAL INVESTIGATION OF THE INFLUENCE OF BIOGENIC EMISSIONS ON OZONE IN SAXONY (GERMANY)

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Biogenic emissions of e.g. terpene and isoprene (emitted by trees, for example) and NO (as a product of microbial degradation) modify the ozone concentrations close to the ground especially in rural areas. These substances are extremely reactive and contribute considerably to the oxidation capacity of the troposphere. This kind of emissions can only be influenced to a certain degree by human beings.
The model system METRAS - MUSCAT - Euro-RADM is used to investigate the impact of biogenic emissions on the ozone concentrations under summer conditions. The model was applied to the area of Saxony (Germany) where major rural areas can be found. Included is a sensitivity study about the influence of the emissions from rape on the ozone production in the model domain because rape is one of the major crops grown in Saxony.

PRODUCTION AND EMISSION OF ACETALDEHYDE IN TREES

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The photolytic and oxidative destruction of the tropospheric trace gas acetaldehyde results in a net production of ozone. Acetaldehyde is either directly emitted into the atmosphere or is produced there by oxidation of hydrocarbons. Besides industry, the combustion of fuels and biomass burning are considered as major sources of atmospheric acetaldehyde. Although acetaldehyde is known to be synthesised in the biosphere by a wide range of organisms, its emission from biogenic sources into the atmosphere is poorly understood. In the present studies we examined the metabolic origin of acetaldehyde and its emission by the leaves of young poplar trees. Treatments which increased the ethanol concentration of the xylem sap significantly enhanced acetaldehyde emission by the leaves. Since plants fed with ^{14}C-radio-labelled ethanol emitted labelled acetaldehyde by the leaves it is assumed that acetaldehyde is synthesised through oxidation of ethanol xylem derived by leaf alcohol dehydrogenase. Further labelling experiments suggested that ethanol delivered to the leaves is produced in anaerobic zones of the roots by fermentation processes. Flooding the root system caused anoxic conditions in the rhizosphere and resulted in significantly increased ethanol concentrations in the xylem sap. From these results it is hypothesised that acetaldehyde emitted by the leaves of plants originates from xylem transported ethanol which is synthesised during alcoholic fermentation in the roots.

PHOTOCHEMICAL SMOG IN SANTIAGO DE CHILE - RELATIONSHIPS BETWEEN PRECURSORS NO_x, CO, NMHC AND SECONDARY COMPOUNDS OZONE AND PAN

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In November and December 1996 a campaign called PHOTOCHEMICAL CAMPAIGN took place in Santiago de Chile covering a range of simultaneous measurements of meteorological parameters and air chemical compounds including ozone, CO, NO_x, PAN and on-line NMHC.
Strong emissions of primary pollutants during stagnant weather conditions lead to a rapid increase of CO, NO_x, and NMHC in Santiago. Intensive global radiation during daytime, temperatures between 30°C-35°C and the specific orographic situation of Santiago de Chile close to the highest mountain ranges of the Andes that leads to the development of a very persisting valley-mountain-breeze system favours the formation of photooxidants through effective consumption of primary pollutants in the course of the day. Similar conditions may be found in the Mediterranean Area as was shown during MEDCAPHOT-TRACE. However, the case of Santiago shows a unique example to study the evolution of photochemical smog since episodes occur almost daily and are pronounced, with high PAN values, a specific indicator for anthropogenic driven photochemistry.

OZONE INJURY SPATIAL PATTERN IN ALEPPO PINE AND AIR POLLUTION DYNAMICS IN THE MEDITERRANEAN.

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Interdisciplinary studies, combining the evaluation of effects with the tracking of photooxidants (i.e. ozone) and the meso-meteorological interpretation of the data, have been carried out in eastern Spain since 1994. Mesoscale circulations are very important from the point of view of how and where forest ecosystems are affected by point sources and regional air pollution in the Mediterranean area. The recirculation processes in the Mediterranean strongly influence the ozone daily and spatial patterns. First results of these field surveys show that during 1994, 95 and 96, visual ozone injury (chlorotic mottle) in *Pinus halepensis* was well correlated with the penetration of the sea breeze in coastal valleys of Castellón. AOT40 calculated for the monitoring stations located in the Mijares valley show values under the threshold (10.000 ppb.h) near the city of Castellón, whereas in the other stations inland along the valley the threshold is surpassed all summer long until September-October. Ozone seems to be able to affect Aleppo pine under different climatic conditions. And chlorotic mottle can be used as a field indicator of the degree of ozone effects, even in different climatic conditions. Finally, a higher percentage of chlorotic mottle is present in needles of *Pinus halepensis* from the valley localities closer to the seashore, where the seabreeze entrance is more frequent during the whole year. This mechanism brings high ozone levels inland from the coast.

DAILY OZONE PATTERNS AND AOT40 INDEX IN EAST COAST OF THE IBERIAN PENINSULA

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The complexity of air mass dynamics in the Mediterranean has already been quite well documented in several EU research projects conducted in the area since 1989 (MECAPIP, RECAPMA and SECAP).It is clear now that the recirculation processes involved, in which new emissions (NOx and other precursors) are incorporated, strongly influence the daily and spatial ozone patterns in the Mediterranean. In this sense, the results from the Valencian Community air quality network, show that within a natural pathway of air mass transport (e.g. a valley) three different O3 diurnal patterns are clearly distinguished: high elevation, medium and coastal sites. High altitude sites are characterised by maintaining an almost constant high O3 level throughout the day (no diurnal cycle). Low altitude sites have maximum levels coinciding with daylight hours and close to zero O3 levels at night (diurnal cycle). At the medium altitude sites the maximum values occur in the daylight hours; however, O3 levels never drop to zero. These different patterns change in the narrow range of 50 to 60 km (smaller than the minimum EMEP model grid of 50 or 150km), which implies a huge spatial variability in the area. AOT40 index for 3 and 6 months are calculated as a running value trough the year and compared for the different O3 patterns. Also, several daylight windows have been used in the AOT40 calculations in order to check the sensibility of the index to the time window choice and to the different ozone daily patterns compared to the AOT40 calculated for real day hours (radiation>50w/m2). It has been concluded that all daytime windows, produce overestimations in diurnal cycle sites and underestimations in non diurnal cycle sites of the AOT40 values when they are compared with the real day time hours (radiation>50w/m2).

Tropospheric ozone and Sulpher dioxide in Cairo atmosphere.

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Surface ozone (O3) and sulpher dioxide (SO2) gas were evaluated in the atmosphere of a residential site at Cairo (30.05 N , 31.17 S) from October 1994 to March 1995. This work discuss sources of ozone and sulpher dioxide in the atmosphere particularly with regard to the relative contributions of fluxes from the stratosphere and that created due to photochemical reactions. Hourly concentration of SO2 shows that the maximum value was at 9 am. associated with traffic emissions which is a major source of SO2 in this period and residential area. The diurnal variation of ozone concentration exhibits it peak values in the afternoon which indicate a strong contribution of photochemical smog.

THE ROLE OF ANTHROPOGENIC AND BIOGENIC EMISSIONS ON TROPOSPHERIC OZONE FORMATION OVER GREECE

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In this study an attempt was made to examine the response of a grid-based photochemical model on the simulated tropospheric ozone levels for various emission patterns. More precisely, the role of the biogenic emissions to the tropospheric ozone formation over areas with significant anthropogenic sources is investigated. The area of interest is the SE part of the Greek Peninsula where there are various types of anthropogenic pollutant sources including large urban areas, major industrial installations, power plants, main traffic routes and it is covered by various types of forests in a large extent.

For this purpose ozone air quality simulations were performed using the combined system of the atmospheric model RAMS and the photochemical model UAM. Simulations were performed using various emissions scenarios with and without the implementation of biogenic inventories.

Solar effective UV irradiance at height levels form the surface to the tropopause

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Measurements of the solar biologically effective UV radiation were carried out during the period from 7 to 14 June 1997 by using a radiometer flown on a Falcon aircraft, at several altitude levels, from sea level up to 13 Km. The results showed that an increase occurs of about 8-13% per kilometer throughout the troposphere in the biologically effective UV radiation.This increase has been compared with the burden ozone content at each height level as it was derived from concurrent ozone measurements obtained from ozonesonde ascents. This comparison showed a strong correlation between the biological effective UV radiation and the total ozone content above the UV measurement height level.

On the role of the Lower-Stratospheric Circulation to the Vertical Ozone Structure

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The examination of the role of the lower stratospheric circulation to the vertical ozone distribution, is attempted by using the vertical ozone profiles collected by balloon-borne sondes released at Athens, Greece (38 N, 24 E), throughout the period 1989-1997. The most pronounced features of the ozone structure, such as lamination phenomenon, minimum of ozone partial pressure at the height region of 14-17 km and ozone minima at the height region of 20-25 km, have been used in order to create groups of relevant profiles. The occurrence of the above mentioned features, correlated with the circulation pattern, leads to the following preliminary results: a) Laminated features are associated with the north-northwest circulation in the lower stratosphere; b) The lower stratosphere?s characteristic ozone minimum is related to the influence of the subtropical jet stream circulation; and c) The observed ozone depletion at the height region of 20-25 km, is characterized by the movement of the polar vortex to the mid-latitudes, resulting more intense north-western circulation above our experimental site.

ON THE ROLE OF SEA SALT PARTICLES IN POLLUTED MARINE AREAS

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The reactions of gaseous N2O5 and ClNO3 with Solid NaCl, Solid NaBr and mixed NaCl-NaBr are increasingly recognised as significant in polluted areas. In this study an attempt has been made to examine additional reduction processes by using the interconnection of entropy and enthalpy for various processes with well known macroscopic properties of the bulk solid at temperatures300K.

VERTICAL OZONE DISTRIBUTION IN THE TROPOSPHERE AT ATHENS GREECE

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Measurements of vertical ozone distribution of the tropospheric ozone over Athens Greece (38 N, 24 E) during the 1995-96 winter period are correlated with the prevailled meteorological conditions. In particular, ozone concentration at the troposphere at Athens as deduced from ozonesounding observations are discussed with regard to the transport at the 700 hPa level. Analusis results show that the free tropospheric ozone concentration is affected by the general circulation pattern, with variations of the order of 10%.

THE ROLE OF WATER VAPOUR ON THE TROPOSPHERIC OZONE DEPLETION

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A plaussible relationship between the fluctuations of Ozone concentration and the water vapour mixing ratio at the Athens troposphere is detected. To reach this target, measurements of both, ozone concentration and relative humidity are used by utilising the five years record (1993-1997) of ozonesoundings regurarly performed at Athens Ozone Station. Furthermore, the invention of a theoretically deduced mechanism is finally attempted to illustrate the experimentally derived relationship.

CLOUD IMPACT ON SURFACE ULTRAVIOLET RADIATION

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One can suppose that surface UV-irradiance may increase slightly under condition of small cloud amount comparing the case clear sky by reason of reflection and scattering of solar radiation from cloud sides. Then, with growing of cloud amount, surface UV-irradiance decrease. The elaboration of three-years set of data of UV-irradiance measured in St.-Petersburg and Athens is undertaken. The influence of solar zenith angle is taken into account. The dependence of surface UV-irradiance on cloud amount and solar zenith angle is presented.

SURFACE OZONE MEASUREMENTS OVER ATHENS BASED ON THE HISTORICAL DATA FOR THE PERIOD 1901-1940

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A unique data base for surface ozone concentrations over Athens Greece, for the period 1901-1940 is available based on observations made at the National Observatory of Athens, by using DeJames colometric papers. There-evaluation of these data denotes that during the first half of the 20th century, surface ozone concentrations varried around 20 ppb, with maximum values occured during late spring-early summer period and minimum values during late Autumn period.

ST15 Atmospheric ozone (joint with OA)

Convener: Hirschberg, M.-M.

05 Ozone as a climate gas

Convener: Shine, K.P.
Co-Convener: Hauglustaine, D.A.

OZONE: RADIATIVE FORCING AND CLIMATE SENSITIVITY

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We present a series of general circulation model experiments with prescribed ozone perturbations in different vertical intervals. Both the radiative forcing on the tropopause and the near-surface temperature are used as diagnostic quantities. The climate sensitivity, i.e. the surface warming per unit radiative forcing, and its dependence of the hight of the ozone perturbation are calculated. The model used is Arpege and all experiments are integrated under perpetual January conditions.
A large value of the climate sensitivity and a corresponding large positive feedback are found for perturbations of the upper stratosphere. This should be compared to the relative weak positive feedbacks found both for ozone perturbations in the lower stratosphere and in the troposphere and in a doubled CO_2 experiment. The climate change is analysed primarily by studying the changes in the energy balance at the surface and the related changes in the hydrological cycle. The influence on the climate sensitivity of the definition of the tropopause level as well as of the definition of the radiative forcing is investigated.

LONGITUDINAL DIFFERENCES IN SEASONAL OZONE CHANGES OVER NORTHERN MIDLATITUDES

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Time series of total ozone seasonal (winter-spring and summer) means from European Dobson stations and those from the United States and Canada have been analysed. For each of the considered stations, the mean values for both seasons are positively correlated and their differences decrease. The correlation coefficient values are significantly greater for the Northern American stations than for the European stations, indicating a longitudinal dependence of seasonal variation of total ozone. Its correspondence with seasonal variation of the Brewer-Dobson circulation cell is suggested. Taking into account the fact that the winter-spring and summer total ozone means are well correlated over North America, it is possible to use in this region the winter-spring mean value as a predictor to infer the summer mean value. This may be useful in making an early estimate of potentially excessive solar UV radiation during the summer months.

THE EFFECT OF A MORE REALISTIC OZONE DISTRIBUTION ON CLIMATE SIMULATION WITH A GCM

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So far, the background ozone field used for climate simulations with the ECHAM GCM in Hamburg, was derived from an analytical formula which calculated ozone profiles as a function of total ozone and ozone peak height distribution. To assess how a more realistic ozone distribution might influence the simulated climate, a new zonal monthly mean ozone climatology, based entirely on ozonesonde and satellite observations over the target period 1980-1991, was built into ECHAM and run in an uncoupled mode using prescribed sea surface temperatures. The results are compared to those of a similar control run using the previous ozone climatology. A short summary of the new ozone climatology characteristics and its differences with regard to the previous climatology will be presented, followed by an overview of the main results from the two control runs. It is found that the systematically lower ozone values of the new climatology around the tropopause leads to lower temperatures here, accompanied by increased convection and high cloudiness epecially in the Tropics. The influence of the ozone hole over Antarctica - in contrast with the ozone spring maximum of the previous climatology - is mainly a cooling and intensification of the polar vortex in October, but also in November when the ozone hole has almost recovered. The results from the control runs are compared with re-analyses from ECMWF.

IMPACT OF ANTHROPOGENIC ACTIVITIES ON TROPOSPHERIC OZONE

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The budget of ozone and its evolution resulting from anthropogenic activities are simulated with a global three-dimensional chemical-transport-model, called MOZART (Model of OZone And Related chemical Tracers). MOZART is developed in the framework of the NCAR CCM2 and considers a comprehensive tropospheric chemistry including non-methane hydrocarbons. It calculates the distribution of 56 chemical species with a resolution of 2.8 degrees in both latitude and longitude, 25 levels on the vertical (from the surface to the upper stratosphere) and a time step of 20 min.
In this paper, we present the changes in tropospheric ozone and its precursors (CH_4, NMHCs, CO, NO_x) since the pre-indutrial period. The ozone change at the surface exhibits a maximum increase at mid-latitudes in the northern hemisphere reaching more than 40–50 ppbv over Europe and the southeastern US during summer. The possible evolution of ozone in year 2050 is also calculated with the model based on estimated future scenarios. The impact of the present-day and future aircraft fleet on nitrogen species and ozone is also included in our simulations. The impact of these past and future ozone changes (including aircraft emissions) on the radiative forcing of the climate system are discussed. The seasonal and geographical distributions of the radiative forcings are illustrated.

THE TROPOSPHERIC CARBON MONOXIDE DISTRIBUTION IN THE NORTHERN TEMPERATE BELT AS THE 2-D MODEL CALCULATION RESULT

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The carbon monoxide and ozone with other minor constituents concentration in the 0-16-km layer and in the 30°-60° N belt is calculated by the 2-D (height-longitude) nonstationary photochemical model with climatic zonal and vertical fixed transport. The concentrations of 32 atmospheric species are calculated, about 170 atmospheric reactions among oxygen, hydrogen, nitrogen, carbon, chlorine and bromine compounds during diurnal course are considered.
The geographical inhomogenity of the surface carbon monoxide releases and their seasonal variability are accounted. The climatic data of tropospheric humidity and rains from "The NCEP/NCAR 40-year reanalysis project" are used. The distinction between water vapor content values over land and ocean determines generally nonhomogeneous distribution of hydroxyl radical. The carbon monoxide spatial inhomogenity is due to the inhomogenity of both its sources and hydroxyl as the main carbon monoxide destroyer. The model results are discussed and compared with observations.

TRENDS IN TROPOSPERIC AND LOWER STRATOSPHERIC OZONE IN EUROPEAN ARCTIC

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Ozone sonde time series from Sodankylä Observatory of the Finnish Meteorological Observatory is put through a statistical analysis of long term changes from 1988 to 1997. Careful attention is paid on data quality, concentrating on pre-flight calibration records and comparative column data. Sodankylä data form the longest continuous ozone sonde series in the European Arctic, at present there are 640 ozone soundings in the series. Finnish data indicate ozone decrease in the troposphere of the order of 1..3% per year since late 1980's. Results of statistical analysis are compared to other studies of ozone trends.

PRESENT-DAY AND FUTURE IMPACT OF AIRCRAFT INDUCED OZONE CHANGES

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Aircraft induced NO_x emissions lead to significant modifications of the atmospheric ozone concentration. Hence, an additional radiative forcing is provided to the climate system. It has been shown that the resulting climate impact is also significant, even for present-day subsonic air traffic. This is demonstrated by equilibrium climate change simulations with a comprehensive 3D model of the atmosphere ocean system.
However, it appears that the relation between the radiative forcing and the climate change (in terms of surface temperature change) in the ozone sensitivity experiments is not as straightforward as it is usually found in greenhouse gas experiments. Even for present-day aircraft conditions, for which the ozone perturbation is largely restricted to the middle and upper troposphere, a considerably nonlinear dependence of the global mean temperature response from radiative forcing can be found.
For future aircraft scenarios (assuming the existence of a commercial stratospheric air-fleet) , for which the lower stratosphere ozone distribution is also affected, the radiative forcing seems to be a bad predictor of climate change.

LOWER STRATOSPHERIC TEMPERATURES AND THEIR RELATIONSHIP WITH OZONE TRENDS

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Subjectively analysed data from the Freie Universität Berlin (FUB) are used to illustrate the changes in the thermal structure of the lower-middle stratosphere over the past four decades. Annual mean temperatures in the Northern Hemisphere reveal a pronounced cooling, which is not well described by a linear trend. The cooling has accelerated since 1993, following a warming caused by the radiative effects of volcanic aerosols from the Mt. Pinatubo eruption in 1991. Lower stratospheric temperatures from the Microwave Sounding Unit, available since 1979, give independent confirmation of this cooling. There is a clear connection between the recent accelerated temperature decrease and total ozone changes. This is shown to be broadly consistent with the reduced heating in the lower stratosphere and has implications for the radiative energy input into the upper troposphere.
Some of the possible feedbacks will be discussed. Closer examination of the temporal and spatial structure of the cooling reveals an apparent trend in the springtime, which allows the possibility of increased ozone destruction resulting from heterogeneous chemical processes. Some attempts to separate the causality of the temperature and ozone decreases will be presented; effects on the radiative forcing of the troposphere in Northern Spring will be discussed.

EXPERIMENTS EMPLOYING OZONE CHANGES IN A GENERAL CIRCULATION MODEL

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The effect of ozone change on the climate is investigated using the Intermediate General Circulation Model (IGCM) developed at Reading. Several ozone change experiments have been performed, ranging from simple idealised scenarios to rather more realistic ozone perturbations. The simpler scenarios investigate the effect of idealised perturbations to the ozone profile at various different altitudes, whilst the more realistic experiments include (a) employing climatological ozone adjusted to fit TOMS observations and (b) employing observations of ozone change throughout the depth of the troposphere and stratosphere. In each case the effect on the stratospheric circulation and temperature trends, both in the stratosphere and at the surface, is examined.

LÉVY FLIGHTS BY PHOTONS IN CLOUDY SKIES ? IMPLICATIONS FOR THE SW-HEATING OF TROPOSPHERIC OZONE

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Recently theoretical and observational studies have highlighted that under 'real' inhomogeneous or fractal cloudy sky conditions the photon geometrical paths are α-stable Lévy-distributed, which is different than implicitly or explicitly assumed in non-statistical plane parallel homogeneous radiative transfer (RT) models. Since for Lévy type transport statistics, the probability density functions of optical paths (PDF-OP) is different than modelled using non-statistical RT-models, the SW-solar radiation absorption is likely to be altered. In particular, Lévy type transport statistics favour shorter and extremely long geometrical paths at the cost of medium long geometrical paths. This is an intermittency effect, characteristic for transport processes in turbulent media. In consequence of the L'evy type PDF-OP occurring in fractal clouds, the relative contributions of the strong and weak SW-absorbers to the total atmospheric SW-absorption is altered to the ones calculated using conventional RT-models.
Here observational evidence of Lévy transport statistic under cloudy sky conditions is given, and the consequence for the SW-absorption of a weak absorber - tropospheric ozone in the visible wavlength range - is discussed.

CHANGING DISTRIBUTION OF TROPOSPHERIC O_3 AND ITS RADIATIVE FORCING OF CLIMATE: PAST, PRESENT, AND FUTURE

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To assess the possible climate effects of anthropogenically enhanced O_3 in the troposphere, it is essential to distinguish the contributions by natural and anthropogenic processes to the O_3 distribution. With a coupled chemistry - general circulation model (ECHAM4), we calculate the contributions to tropospheric O_3 levels by stratosphere-troposphere exchange (STE) and by photochemical production in the troposphere for pre-industrial, present-day and future (IS92a) emission scenarios. The model simulates background tropospheric CH_4-CO-NO_x-HO_x photochemistry, emissions of CO and NO, and wet and dry deposition. The simulated present-day seasonality of surface O_3 compares well with observations. Stratospheric O_3 contributes significantly to the seasonality of surface O_3, especially in the extratropical SH and in relatively clean areas in the NH. We calculate an annually average tropospheric O_3 burden of 190, 270, and 332 Tg O_3 for the pre-industrial, present-day, and future scenarios, respectively. The contribution of O_3 from stratospheric origin is about 110 Tg and does not change significantly, so the calculated increase of O_3 is associated with photochemical production resulting from anthropogenic emissions of O_3 precursors. The O_3 increase maximizes in the free troposphere where O_3 lifetimes are relatively long compared to the boundary layer, and the climate effect is relatively strong. The calculated radiative forcing at the tropopauze is 0.38 W m^{-2} for the present-day scenario and 0.69 W m^{-2} for the future scenario.

THE TIME EVOLUTION OF TROPOSPHERIC OZONE RADIATIVE FORCING

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The UK Meteorological Office off-line chemistry-transport model (STOCHEM) has been used to perform 3-D simulations of the atmospheric composition at various times: 1860, 1950, 1970, 1990, 2015, and 2050. These simulations were carried out using best estimates of emissions and using present day meteorological fields from the Hadley Centre AGCM. The model includes the chemistry and photochemistry of 70 species, including CH_4, NO_x, CO and 10 NMHCs, including isoprene, and dry and wet deposition. The model took part in the GIM model inter-comparison, and produced a reasonable simulation of present-day tropospheric O_3. Tropospheric O_3 changes since 1860 from these model simulations have been inserted into a radiation code, to calculate the time evolution of the radiative forcing due to increases in tropospheric O_3. Aircraft NO_x emissions are shown to have a significant impact on upper tropospheric O_3 and radiative forcing. Further simulations, using a 2xCO_2 meteorology, suggest a large negative feedback of the climate on the O_3 change, due to increased temperatures and humidities, and changes in the circulation.

ST17 Aviation and space flight (joint with OA)

01 Aviation impact on the atmosphere

Convener: Kelder, H.
Co-Convener: Sausen, R.

The IPCC Special Report on Aviation and the Global Atmosphere: the impact of future subsonic aircraft emissions.

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Using a host of 3 dimensional global tropospheric models the impact of future sub-sonic aircraft emissions on the concentrations of O3, OH and NOx was estimated for the years 1992, 2015 and 2050. These model calculations will be used for the forthcoming IPCC Special Report on Aviation and the Global Atmosphere. The models differ in their formulation of vertical and horizontal resolution, transport, boundary conditions and chemistry. Therefore, inter-model differences are large. We will discuss model results and the most important uncertainties.

IS THERE ANY OBSERVABLE INCREASE IN CIRRUS CLOUD DUE TO AVIATION DURING 1982–1991?

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Emissions of exhaust aerosol and water vapour by aircrafts are responsible for the formation of condensation trails (or contrails). Exhaust aerosols may also indirectly alter cloudiness by increasing the occurrence of 'natural' cirrus. We analyze synoptic cloud reports from ships and land stations for the period 1982–1991, a decade of large increase in the total fuel consumption by aviation. The changes in cirrus cloud occurrence and cirrus cloud amount are estimated from the surface observations and a relation is sought with the geographical distribution of aviation fuel consumption.

EFFECTS OF ATMOSPHERIC TEMPERATURE FLUCTUATIONS WITH ESTIMATION OF SUPERSONIC AVIATION IMPACT ON OZONE LAYER OF THE EARTH

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A two-dimensional zonal-average model of diabatic circulation and gaseous and aerosol composition of the troposphere and stratosphere is used to examine a role the atmospheric temperature fluctuations play for estimates of 1990-2015 changes occurring in the ozone layer as a result of NO_x, SO_2, CO_2, CO, and CH_4 emissions from supersonic aircraft. The model uses the zonal mean temperature ($\bar{T}$) variations derived from a temperature probability distribution. This distribution was obtained from the US National Meteorological Center's temperature data. We show that the atmospheric temperature fluctuations are very important for the estimates of supersonic aviation effects on ozone in both middle and high latitudes of the Northern Hemisphere. For example, a scenario for chlorine background $3ppbv$ with 100% gaseous SO_2 and NO_x injections from supersonic ($2.4Mach$) aircraft with emission indexes of $0.4g$ and $15g$ per $1kg$ fuel, respectively, results in the relative total ozone change of −0.47% at 45°N and −0.71% at 70°N in March, without account taken for $\bar{T}$ variations, and 0.75% at 45°N and −1.32% at 70°N, with $\bar{T}$ variations taken into account. The same scenario with SO_2 injection as 100% aerosol sulfate particles of $0.01\mu m$ radius results in the relative total ozone change of −1.05% at 45°N and -1.32% at 70°N, without account taken for $\bar{T}$ variations, and −1.35% at 45°N and −2.50% at 70°N, with $\bar{T}$ variations taken into account.

THREE-DIMENSIONAL MODELING STUDIES OF THE IMPACT OF AIRCRAFT EMISSIONS ON ATMOSPHERIC OZONE: SENSITIVITY TO EMISSION INDICES, H_2O, AND SULFUR CONVERSION

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The NASA Langley three-dimensional chemistry transport model (CTM) is used to examine the impact of future subsonic and supersonic aircraft emissions on ozone. The model includes a full representation of stratospheric chemistry as well as parameterizations treating the reactions occurring on polar stratospheric clouds and on sulfate particles. Multiple simulations using scenarios from the recent Intergovernmental Panel on Climate Change (IPCC) model intercomparison have been conducted with the Langley CTM to characterize the response of ozone to varying aircraft NO_x emission indices, the efficiency of sulfur conversion to sulfate particles in the exhaust, and the emission of H_2O. The inclusion of H_2O engine emissions significantly increased the calculated aircraft impact on ozone compared to a calculation with only NO_x emitted, particularly at low NO_x emission indices. Engine sulfur conversion to sulfate particles also led to larger ozone decreases. Recent assessments of the effects of stratospheric aircraft on the atmosphere have emphasized the need to quantify the uncertainties in model predictions. We will compare and contrast our calculations to other 2- and 3-D model studies and examine the principle sources of uncertainties.

IMPACT OF SUBSONIC AIRCRAFT ON ATMOSPHERIC CHEMISTRY: MESOSCALE SIMULATIONS ON THE ROLE OF HETEROGENEOUS REACTIONS ON/IN SULFATE AEROSOLS

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The global amount of emissions from subsonic aircraft is to a high fraction released in the tropopause region. Many model studies suggest that in this altitude range aircraft induced NOx changes result in a significant increase of ozone. However, the influence of heterogeneous chemistry on the impact of subsonic airtraffic is currently not well understood. Sulfuric acid aerosols (SAA) contribute to a large extent to the aerosol burden of the lower stratosphere and the upper troposphere. In the present study Box- and 3D-mesoscale simulations are performed to elucidate the role of heterogeneous reactions on and in SAA in the chemical perturbations of the tropopause region caused by subsonic aircraft. For these calculations the EURAD-TS model system is applied which has been modified to enable the simulation of atmospheric distributions of SAA as well as heterogeneous conversions of several nitrogen-, chlorine- and bromine compounds on/in SAA. The considered heterogeneous chemistry generally reduces the chemical life time of the NOx exhaust. Despite this, in most simulated cases the aircraft induced ozone increase is enhanced strongly which is a consequence of important modifications of the NOx, HOx, ClOx and BrOx budgets caused by heterogeneous reactions. The simulated aerosol effects show considerable variations with altitude, season and aerosol loading.

THE IMPACT OF NO_X AIRCRAFT EMISSIONS ON ATMOSPHERIC COMPOSITION AND CLIMATE

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Changes in NO_x and ozone concentrations due to aircraft emissions, modelled with the dynamic-chemical general circulation model ECHAM3/CHEM, for the years 1992, 2015 and 2050 are presented. An estimate for the impact on climate will be given.
One of the most important sources of NO_x in the upper troposphere are the emissions by aircraft. Since the ozone production in that area is largely controlled by NO_x, aircraft emissions have the potential to change significantly the distribution of the greenhouse gas ozone and temperature.
The paper especially concentrates on spatial and interannual variations of the NO_x background and aircraft NO_x pertubations as well as their possible changes in the future due to climate change.

ANALYSIS OF 24 YEARS OF BALLON-BORNE AEROSOL DATA TO DETERMINE THE EFFECTS OF SUBSONIC AIRCRAFT

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The University of Wyoming balloonborne aerosol record, which spans approximately 26 years (1971-1997), was analyzed to determine possible effects of commercial aircraft on the 8.6 - 12.7 km (29 - 41 kft) altitude range of the atmosphere. An effort to identify condensation nuclei (CN) layers relative to seasonal background conditions in the commercial airlanes was undertaken. Generally, aircraft flight information is not available for past balloon soundings thus making it impossible to ascribe a source to observed CN layers. Under conditions coordinated with the U. S. Federal Aviation Administration, a CN layer observed in March 1997 was traced to a particular aircraft, thus supporting the hypothesis that at least some of the observed layers are contrail remnants. Using the Laramie data set, an attempt was made to quantify the enhancement of aircraft-induced CN layers in comparison with natural background levels. We estimate conservatively that the contribution of the commercial aircraft fleet in the vicinity of Laramie, Wyoming amounts to about 5-13% of the natural background, depending on season.

NON-INTRUSIVE INFLIGHT INVESTIGATION OF AIRBUS A340 ENGINE EMISSIONS

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Passive mode Fourier transform spectrometry is used to perform non-intrusive measurements of jet engine emission indices. For the first time investigations of this kind were made on board of a commercial wide body aircraft. In cooperation with Airbus Industrie the customized and flight approved MIROR spectrometer was installed in the cabin of an Airbus A340. Test flights at various flight and engine conditions were performed from Toulouse/F focusing on the emission indices of the plume species NOx and CO, and the gas temperature close to the nozzle exit.

Results of this campaign and the comparison with emission data calculated from ground-to-altitude models will be presented.

MODEL STUDY OF ATMOSPHERIC POLLUTION BY AVIATION ENGINES IN THE NORTHERN TEMPERATE BELT

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The spatial and temporal courses of NO_X and HNO_Y content field formation over the northern temperate belt due to the transport aircraft flights intensity there in summer and winter and their diurnal schedule are evaluated as deviations from the zonal homogenity used in the 2-D photochemical models of the zonally and diurnally averaged atmosphere for the aircraft exhaust atmospheric effects. The transient 2-D photochemical model of tropospheric photochemistry and climatic air transport in the temperate belt (30° to 60°N) is used. The photochemical block includes about 170 gasphase and heterogeneous reactions among oxygen, hydrogen, nitrogen, carbon, chlorine and bromine species. Relevant up to 30-70% reductions in the NO_X emission are calculated for the 2-D model sources of zonally averaged exhaust product. The NO_X oxidation rates into HNO_3 and HNO_4 are rather high and sensitive to the ambient air temperature, but much lower during the nighttime.The influence of both the emitted NO_X and CO as exhausts products on the ozone, hydroxyl radical and other species behavior and on the redistribution of nitrogen compounds are discussed.

Remote measurements of aircraft exhaust gas using FTIR spectrometry at industrial test-rigs

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Remote measurements of aircraft exhaust gas using FTIR spectrometry were performed in-flight under cruise conditions several times up to now (e.g. Haschberger and Lindermeir, JGR 101, 25,995-26,006, 1996 and Haschberger and Lindermeir, JRL 24, 1083-1086, 1997). For comparison and validation purposes FTIR measurements at an industrial test-rig were performed at ground conditions within the EU project AEROJET. These experiments were carried out with the same spectrometer that was used for the flight campaigns. The poster will present results which were obtained by applying different experimental setups for the detection of H2O, CO2, CO, NO, and NO2.

CHEMICAL CONVERSION OF AIRCRAFT EMISSIONS IN THE DISPERSING PLUME: CALCULATION OF EFFECTIVE EMISSION INDICES

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A box model representative for a mesoscale volume and three different plume models are used to estimate the chemical conversion of exhaust species of a subsonic aircraft at cruise altitude. Clearly deviating results have been obtained for instantaneous mixing of the exhaust in a large scale box and gradual dispersion of a plume. The effect of varying daytime of release as well as the impact of changing dispersion time is studied with emphasis on the aircraft induced O_3 production. Effective emission indices are calculated for O_3, NO, HNO_3 and HNO_4. These effective emissions enable a correction for expanding plume effects in global or mesoscale models. The dependence of necessary corrections is investigated for different grid sizes.

THE IMPACT OF AIR TRAFFIC IN THE NAFC: MODEL RESULTS VERSUS MEASUREMENTS

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The impact of aircraft emissions on the atmospheric composition has been investigated with a global chemistry transport model. The model calculations show that aircraft emissions contribute to about 40-80% of the background values of nitrogen oxides in the North Atlantic flight corridor and lead to an increase of the background ozone concentrations about 3-4% in winter and 5-7% in summer. The three-dimensional distributions of ozone, nitrogen oxides and nitric acid, calculated by using analyzed meteorological data, have been compared with airborne measurements performed in the North Atlantic flight corridor as part of the EC POLINAT project. The agreement between modelled results and observations is reasonably good. The perturbation of nitrogen oxides caused by aviation is expected to be observable due to its large magnitude, but the resulting ozone perturbation will in general be to small too distinguish it from the natural variability.

PARAMETRIZATION OF CONTRAILS IN A CLIMATE MODEL

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Sensitivity experiments with a comprehensive 3D climate model have shown that persistent contrails bear the potential of a significant climate impact. However, quantitative estimations of this impact require the use of a parametrization scheme, where contrails at some model grid box should depend on the instantaneous atmospheric state. Such a scheme has not been available for previous simulations.
We have developed two ways of parameterizing the coverage due to persistent contrails, both of which rely on the assumption that supersaturation with respect to ice may occur in part of some model grid box although the mean humidity value is below the saturation point. The first parametrization idea has been derived from (and is similar to) the cloud scheme of the climate model (ECHAM), the second one uses humidity measurements to derive characteristic values for humidity fluctuations within grid boxes of a size typical for the model's spatial resolution. The parameterized contrails obtain individual optical properties, which are calculated independently from those of natural cirrus in the same grid box. Optical depth and effective particle size associated with the simulated contrails are checked with results of a microphysical boxmodel.

UPPER TROPOSPHERIC HO_x: SOURCES AND ROLE IN THE AIRCRAFT IMPACT ISSUE

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The injection of nitrogen oxides (NO_x) by aircraft is believed to enhance ozone production in the upper troposphere. However, ozone production depends on the availability of odd hydrogen radicals, HO_x. While the main production of HO_x in most of the troposphere is the O^1D+H_2O reaction, where O^1D is supplied by ozone photolysis, recent work showed that other sources are important in the very dry upper troposphere. Proposed sources are the photolysis of acetone and convectively injected peroxides. We use a global model to determine the relative importance of the different HO_x sources in the upper troposphere. The model suggests that 1/ ozone photolysis is the largest source at high latitudes, 2/ acetone generally plays a limited role, 3/ convection of peroxides (mostly CH_3OOH) and aldehydes are the dominant sources in the Tropics. The uncertainties, as well as the implications for the aircraft impact issue are discussed.

EMERGING NEW ATMOSPHERIC CHEMISTRY OF NITRIC OXIDE AND ITS IMPLICATIONS FOR THE AVIATION IMPACT ON THE ATMOSPHERE

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Assessment of the impact of aviation on the atmosphere (e.g., POLINAT & SONEX campaigns) is critically dependent on the accuracy of our knowledge about the sources and sinks of NO in the upper troposphere. This paper will therefore discuss a new source of NO which is predicted by shock tube data on the loss of NO and has now been experimentally confirmed (Zipf & Prasad, a paper in press in SCIENCE). This stratospheric source, which involves N_2 and O_2 directly (i.e., without the intermediary of N_2O) would considerably increase the flux of NO from the stratosphere into the upper troposphere. The new source also implies possible existence of an unrecognized sink of NO_Y, since the current models already overestimate the NO_Y even without the new source. Both implications could be important for POLINAT/SONEX. In addition, we will also discuss two other potential sources of NO_X involving the photodissociations of the N_2OO_2 (from the $N_2O + O_2$ (b) + M) and $N_2O{\cdot}O_3$ complexes. These sources are attractive since their strengths maximize in the 5 to 10 km region at values ≈1000 and 120 NO_X cm^{-3} s^{-1} respectively. It is hoped that the discussion will motivate the needed experiments.

3D STRATOSPHERIC MODELLING OF THE FUTURE EFFECTS OF AIRCRAFT EMISSIONS

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The upper troposphere and lower stratosphere are regions of great importance for ozone chemistry and climate change. Future emissions of nitrogen oxides from supersonic aircraft are predicted to further decrease ozone levels in an already depleted ozone layer.
We have used a 3D stratospheric model, SLIMCAT, to investigate the effect of future aircraft emissions in the years 2015 and 2050. The model was run for 18 months and the results form part of the model intercomparison for both the IPCC report on aircraft emissions and the EU AEROCHEM project. The SLIMCAT model is an isentropic off-line Eulerian transport model, where 'vertical' velocities are calculated using the Middle Atmosphere Radiation scheme (Shine, 1987) from the UGAMP Stratosphere Mesosphere Model.
The results of the SLIMCAT model are presented and the effect of future aircraft emissions on the distribution of chemical species during northern hemisphere winters is discussed. Model output using interactive ozone values to calculate diabatic heating are also compared to results using a climatological ozone field.

THE POLINAT-2 EXPERIMENT: A STUDY OF LARGE-SCALE AIR TRAFFIC EFFECTS

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The POLINAT-2 (Pollution from Aircraft Emissions in the North Atlantic Flight Corridor) aircraft field campaign was performed in Sep./Oct. 1997 based from Shannon, Ireland. The objectives of the POLINAT-2 experiment were to investigate large-scale impact of subsonic air traffic in the North Atlantic flight corridor (NAFC), to evaluate the NOx budget in the upper troposphere, and to intercompare chemical aircraft measurements. Using the DLR Falcon a total of 10 missions were flown including north- and southbound survey flights in and around the NAFC. Also measurements during in-service flights of an instrumented Swissair B747 over the North Atlantic were performed. The flight planning was based on meteorological and chemical forecasts of University of Bergen and KNMI, respectively. A key partner in the investigation is the SONEX (SASS Ozone and Nitrogen Oxides Experiment) project which was deploying a NASA DC-8. Coordinated missions with SONEX include formation flights for instrument intercomparison and joint corridor track crossings. A preliminary data analysis indicates that large-scale corridor effects for air traffic NOx were observed.

THE INFLUENCE OF AIRCRAFT EMISSIONS ON THE GEOGRAPHICAL DISTRIBUTIONS OF OZONE AND RESERVOIR SPECIES IN THE UPPER TROPOSPHERE AND STRATOSPHERE

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The UIUC 3-D Atmospheric Chemical Transport model is used to estimate the influence of subsonic aircraft emissions on the geographical distribution of ozone and other species in the upper troposphere and stratosphere. Several 5-year-long steady-state model runs have been carried out for the boundary conditions of 1995 and the wind field derived from the UIUC 24-layer atmospheric general circulation model. A NASA dataset is used to describe the NOx emissions from the present-day subsonic aircraft fleet. The results of the simulations are compared with satellite and airborne measurements to estimate the ability of the model to simulate the ozone and NOy distributions in the upper troposphere and stratosphere. The comparison of model runs with a control run without the aircraft NOx source is performed to estimate the geographical and seasonal distribution of the changes in ozone and reservoir species caused by the aircraft emission. The model results show that the largest influence of aircraft NOx emissions occurs in the vicinity of the Atlantic flight corridor and in the area where heterogeneous reactions on Polar Stratospheric Cloud particles take place. The latter can be explained by the high sensitivity of the polar stratosphere to the changes in the intensity of HNO_3 sources.

IN SITU OBSERVATIONS OF AEROSOL PARTICLES IN JET AIRCRAFT PLUMES

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During the Sulphur 5 experiment in April 1997 fine mode aerosol particle emissions and contrail ice crystal distributions in the near field of the DLR research aircraft ATTAS have been investigated with respect to changing environmental conditions (dry exhaust and contrail), changing fuel sulphur content (20 ppm versus 3000 ppm) and volatile/ non-volatile aerosol fractions. Soot emissions were confirmed being independent from fuel sulphur content, amounting to 1.7E15 [#/kg]. Volatile ultra-fine aerosols larger than 5nm in diameter have been observed up to 2E17 [#/kg] for high sulfur and about 2E16[#/kg] for low sulfur fuel in the dry exhaust. Corresponding numbers in the presence of contrail ice crystals were clearly lower, namely 6E16 and 6E15, respectively. Significantly increasing trends with plume age were found for ultra-fine particles (>5nm) in the low sulfur and for Aitken nuclei (>14nm) in the high sulfur case, but exclusively in dry exhaust plumes. In contrast, a decreasing trend is evident for ultra-fine aerosols in contrail environment, which is consistent with scavenging time scales on contrail ice surfaces. A quantitative model analysis of the observed trends with respect to particle growth mechanisms will be subject of a further study.

A DIAGNOSTIC STUDY OF THE PRESENT AND FUTURE COVERAGE BY CONTRAILS

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The global distribution of the contrail formation potential and the contrail cloud coverage are estimated using ECMWF re-analyses data for temperature and humidity, and several data bases of aircraft fuel consumption (present day and future projections). By means of thermodynamic considerations the probability for the occurrence of persistent contrails is determined. This probability exhibits a rather strong geographical variability, with maxima in the tropics. The mean contrail cloud coverage is computed by multiplying this probability with a suitable function of fuel consumption (linear or non-linear). The product is normalized such that the contrail coverage equals the observed value of 0.5% in a domain between 30°W to 30°E, 35°N to 75°N. The impact of various aircraft emissions scenarios (present day, 2015, 2050) is analysed. Sensitivity studies are made with respect to the impact of propulsion efficiency and flight altitude.

IN-FLIGHT MEASUREMENTS OF AIRCRAFT NON-METHANE HYDROCARBON EMISSION INDICES

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Concentrations of non-methane hydrocarbons (NMHC), CO and CO_2 were measured in exhaust plumes of the DLR experimental aircraft ATTAS equipped with Rolls Royce M 45H Mk501 engines. The emission indices (EI) of individual light NMHC were determined from ratios of NMHC and CO concentration enhancements measured in grab samples and the concurrent in-flight measurements of EI of CO by FTIR emission spectroscopy and/or simultaneous fast continuous measurements of CO and CO_2. Alkenes and alkynes generated by cracking of larger NMHC molecules and aromatic compounds originating from unburnt fuel constituted a larger and a smaller fraction of the NMHC emissions, respectively. The EI(NMHC) were strongly dependent on the engine power setting.

AIRCRAFT NO_X IMPACTS ON TROPOSPHERIC OZONE

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The UK Meteorological Office off-line chemistry-transport model (STOCHEM) has been used to investigate the impact of subsonic aircraft NO_x emissions on tropospheric oxidants. NASA Aircraft emissions estimates for 1992, 2015, and 2050 have been used, whilst surface emissions follow the IPCC is92a scenario. Despite the non-linear chemistry of ozone, the increase in ozone scales nearly linearly with NO_x emissions, suggesting that ozone production in the upper troposphere is strongly NO_x-limited. A strong seasonal cycle is seen in the ozone perturbation due to aircraft NO_x, with a peak in spring. The reasons for this peak are thought to be due to the seasonal cycle in upper tropospheric NO_x, which reaches a peak in the Northern Hemisphere in summer, due to emissions from lightning. In addition, the chemical lifetime of ozone is much shorter in summer, due to the higher radical abundance. More vigorous convection during summer also readily mixes upper tropospheric ozone down towards the surface, where its chemical lifetime is shorter. The impact of PAN chemistry on the ozone perturbation is also investigated, by excluding PAN as a species in simulations with and without aircraft emissions. PAN plays a major role in the determination of background upper tropospheric NO_x.

GLOBAL IMPACT OF A FUTURE HIGH-SPEED CIVIL TRANSPORT (HSCT) AIRCRAFT FLEET ON THE ATMOSPHERIC OZONE COLUMN: A THREE-DIMENSIONAL MODEL SIMULATION

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Multi-year simulations have been conducted with the Langley Research Center (LaRC) three-dimensional, atmospheric Chemical Transport Model (CTM). The model vertical domain (24 levels) extends from the surface through the stratosphere. The model includes a comprehensive treatment of both gas phase reactions and heterogeneous chemical processes on polar stratospheric clouds (PSCs) and sulfate aerosol. Results from a model simulation that includes emissions from a mixed fleet of subsonic and supersonic aircraft with a route structure assumed for the year 2015 will be compared with results from two control simulations for the year 2015 (one assuming emissions from subsonic aircraft only and one assuming no aircraft). All three simulations assume the same background sulfate aerosol loading. The aircraft source emissions (NO_x, H_2O, and sulfates) used in the calculations are taken from a compilation of scenarios developed during the recent Intergovernmental Panel on Climate Change (IPCC) assessments. Results will be presented for the case of an HSCT fleet with an emissions index for nitrogen oxides equal to 5.0 grams per kilogram of fuel and assuming 50% of the fuel sulfur is converted to sulfate particles in the exhaust. Discussion will focus on the the relative importance of the different chemical cycles that destroy ozone and the resultant seasonal and latitudinal perturbations in the column ozone resulting from the aircraft emissions.

ENVIRONMENTAL CONDITIONS FOR LONGLIVED CONTRAILS AS DERIVED FROM MOZAIC DATA

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The European project MOZAIC (Measurement of Ozone on Airbus In-Service Aircraft) provided during the last years a large set of near tropopause environmental data of temperature, ozone and water vapour. These have been subjected to a statistical analysis with the goal to define more precisely the environmental conditions in cases of persistent contrails. To locate such contrails in the very frequented transatlantic flight corridor NOAA satellite quick-looks of the eastern North-Atlantic were analysed for the summer period of 1995. The MOZAIC data of individual flight tracks correspond well to the ice cloud distribution inferred from these satellite images. Cloudy regions are in general connected with high moisture content around ice saturation and low ozone concentration, indicating the tropospheric origin of clouds. Although the measurement level of MOZAIC data cannot be guaranteed to coincide with the height of contrails observed in the satellite images, occasional overlap is suggested by the moisture record of individual flight tracks. These cases exhibit a systematically smaller ozone concentration than contrail free areas. Details of and possible reasons for these observations will be presented and discussed.

A POSSIBLE CHANGE IN CLOUD RADIATIVE FORCING DUE TO AIRCRAFT EXHAUST

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The radiative forcing of natural cirrus clouds from a reduction in the mean ice particle size is presented. The estimated reduction of the mean size in natural due to aircraft exhaust expected in the range between 10 and 30% based on measurements. The im However, the climatic forcing, the weighted sum of SW and LW forcings, depends on mean particle size, surface albedo and the ice water content. It appears that there is a range of diameters between 15 and 25 μm where the climatic response to a change

IN SITU MEASUREMENTS OF NOX IN THE NORTH ATLANTIC FLIGHT CORRIDOR

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Aircraft emissions are a major source of nitrogen oxides in the upper troposphere and lower stratosphere. They are of particular importance due to their potential to modify the net ozone production rate there. In situ measurements of nitrogen oxides in the upper troposphere of single research flights are affected by the high variability of the nitrogen oxides abundance in this region and represent no adequate data base for comparison with simulated NOx fields from models.
Here a data set is presented that comprises more than 30 measuring flights which were performed between July 1994 and July 1996 in the Flight Corridor over the North East Atlantic. For the measurements the DLR research aircraft "Falcon" was used, equipped with NO, NO2, and O3 detectors. A significant seasonal dependence of the nitrogen oxides abundance was found in the upper troposphere. Mean NOx values range between 120 and 280 pptv and 50 and 140 pptv in summer and winter, respectively.
The measured NOx abundance is compared to NOx fields predicted with the general circulation model ECHAM, which was extended by a linear NOx chemistry module. It is found that predicted NOx values compare fairly well with measured NOx values both for summer and winter conditions.

ST17 Aviation and space flight (joint with OA)

02 Air traffic meteorology and weather impact on aviation

Conveners: André, J.-C.; Hauf, T.
Co-Conveners: Carriere, J.-M.; Corjon, A.

"SY.A.G.E. - The French Wake Vortex Spacing System" P. Caisso and J.C. Valentin and A. Corjon

The STNA (Service Technique de la Navigation Aerienne) is performing studies on wake vortices since 1992 for the DGAC (Direction Generale de l'Aviation Civile). Due to limited budget, the work progress is not as fast as expected.
In this paper, we will present SY.A.G.E. (SYsteme Anticipatif de Gestion des Espacements). This system intends to optimise the separation between aircraft at landing and take-off. All the developments done in France are related to this definition.
A first version of SYAGE has been set-up and an experiment aiming at operationaly verifying the system is presented. This first version concerns aircraft at departure and crosswind considerations. Then a windline of seven anemometers has been installed on Toulouse-Blagnac airport to monitor the position of the vortices. This trial should assess the needed accuracy on the wind measurement for an operational system. The constituted wind database will be used to develop short term forecasting compulsory to have the landing version of SYAGE.

ANALYSIS OF THE MICROPHYSICAL DATA IN THE EURICE DATA BASE.

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Aircraft icing remains a significant aviation hazard, especially for turboprop aircraft. and rotocraft because of the lower altitude at which they operate. The EURICE project, partly funded by the EC, has been running for two years. This is aimed at examining current aircraft icing problems and the related certification process.

As part of EURICE, a data base of microphysical measurements has been established by the Project Co-ordinators, CIRA. The data base contains 7000 nm of measurements from the EURICE partners, plus 28000 nm gathered by the FAA. The liquid water content (LWC) measurements cover the range 0 - -39°C and 500 - 25600 feet. The variation of supercooled LWC with altitude, temperature and extent is described briefly in this paper.

An important part of EURICE is the consideration of the accuracy of the current Appendix C icing atmosphere. Results will be presented of a detailed comparison between the microphysical data and Appendix C. Only drops to 50 microns diameter are considered as in the current Appendix C. It is shown that the data are in excellent agreement with the Appendix C supercooled LWC vs. median volume diameter characterization for both stratiform and convective cloud. Poorer agreement will be shown with the Appendix C altitude vs. temperature icing envelope. Finally, the applicability of Appendix C to conditions below 10,000 ft is considered briefly.

Computational Investigation of Aircraft Trailing-Vortex Evolution in Atmospheric Boundary Layers.

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This paper presents three-dimensional large eddy simulations (LES) of civil-aircraft trailing vortices in different realistic atmospheric boundary layers (ABL) with a non-hydrostatic meteorological model. These calculations were performed in order to parametrize an operational model aiming at managing the separations between aircraft at take-off and landing. The problems considered here are taken from twelve selected cases corresponding to trials made at Idaho Falls sponsored by the Federal Aviation Administration (FAA) in 1990. During these trials there was two prevalent meteorological conditions: stable boundary layer and turbulent convective boundary layer. The three-dimensional behavior of the wake vortices (Crow instabilities) as well as the effects of the atmospheric parameters (turbulence, lateral wind, stratification) are discussed. The results of the simulations are compared to experimental data.

Expected Performance of Crosswind-Based Wake Vortex Avoidance Systems at DFW Airport

D. Burnham & R. Rudis

Relaxation of wake vortex separation standards is possible when the ambient crosswind is within certain limits. The feasibility of a wake vortex avoidance system (WVAS) based on such limits depends upon (1) how often suitable crosswinds occur, (2) how long the conditions last, and (3) whether separation changes can be forecast. The paper will analyze five different crosswind-based WVAS, which address landing, takeoff, single-runway and close-spaced-parallel-runway operations. The analysis uses minute-by-minute wind data collected at the Dallas-Ft. Worth Airport.

THE INFLUENCE OF ATMOSPHERIC TURBULENCE ON CROW INSTABILITY INITIATION

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The sinusoidal instability known as the Crow instability is an essential factor affecting the disintegration of the vortex wakes. This instability should be taken into account in the wake vortex decay model intended for the investigation of the second airplane dynamics. The initiation of the Crow instability due to atmosphere turbulence and variable wing loads is considered in the some publications in which the lifespan of a vortex time is estimated. In this investigations it is supported that the wake vortices disappear when the amplitude of vortex line deviations from an initial position becomes equal to the initial distance between them. There are a number of experimental work in which the vortex lifespan is estimated at different turbulence levels. To investigate the second airplane dynamics it is necessary to know not only the lifespan of a trace, but also a spatial position of vortex lines. This position is a random process, the characteristics of which depend on many factors, mainly on atmospheric turbulence. The purpose of this paper is to determine the characteristics of this process. These characteristics can be used to construct an algorithm which generates random realizations of the wake vortex position in space. Such an algorithm can be used for the investigation of the second airplane dynamics.

COMPARISON OF LABORATORY WAKE VORTICES WITH AIRCRAFT VORTICES

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Measurements of wake vortices from both laboratory models and aircraft will be presented. The laboratory measurements were obtained in a water-filled towing tank using model wings. Vortex evolution in the laboratory is followed from generation through decay in three stages: (1) a 2-D line vortex pair, (2) transition from 2-D line vortices to 3-D vortex rings, and (3) development, migration, and decay of vortex rings. The laboratory experiments use both dye (for visualization) and neutrally-buoyant particles (for both visualization and DPIV measurements of circulation). We will present measurements in both nonstratified and stratified flows to show the effects of stratification. Measurements of aircraft vortices, obtained as part of NASA's AVOSS Wake Vortex Program, will also be presented. Simultaneous meteorological measurements will be used to interpret the aircraft wake vortices in terms of nondimensional parameters. We will compare vortex transport and decay from the laboratory and aircraft measurements both to each other and to a modified version of a wake vortex prediction algorithm originally reported by Greene (1986).

Reducing the Impact of Adverse Terminal Weather on Major US Airports with the Integrated Terminal Weather System (ITWS)

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Adverse terminal weather is the major cause of delay at major US airports as well as a significant safety hazard. A fully automated terminal weather decision support system has been developed which combines data for ground and airborne weather sensors as well as national numerical models to provide products which can be directly used by controllers, pilots, traffic flow managers, terminal facility supervisors and automation systems. The current products include predictive wind shear information, storm tracking and extrapolation, storm severity and high resolution gridded winds to improve aircraft sequencing and merging. Operational use of functional prototypes at three major US airports (Dallas, Orlando and Memphis) has shown that delays due to convective weather can be substantially reduced and that better terminal winds information can improve aircraft merging and sequencing during adverse weather. The greatest convective weather delay reduction benefits were found to arise from improved traffic flow management decision making. The paper concludes with a summary of current research underway to further extend the safety and efficiency (delay reduction) benefits.

AMETIS1 SYSTEM FOR WINDSHEAR AND INVERSION WARNINGS AT THE ZURICH-AIRPORT

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Wind shears and inversions are especially during landing or take off a meteorological danger for the aviation. AMETIS1 (Aeronautical METeorological Information System) is a ground-based observing system which collects temperature, dew point and wind data from several surface stations at different heights on hills surrounding Zurich airport. With these data wind shear and inversions are calculated and displayed on a screen in color depending on the degree of danger for aviation. If defined threshold values are reached or passed, an acoustic signal is emitted and a wind shear or inversion warning is issued.

Since 1988 AMETIS1 is operational and data from exceptional weather situations concerning wind shear or inversions were collected and analysed. An example for a weather situation with wind shear is the foehn wind that reaches the airport aera and produces wind shears of 8 KT in a layer between 1450 ft/GND and 2000 ft/GND and an inversion of 9° C between ground and 300 ft; another example for a strong inversion up to 16° C is a high pressure system during winter in a layer between 1450 ft/GND and 2300 ft/GND.

EFFECTS OF WEATHER ON AIRCRAFT WAKE TURBULENCE EXPERIENCED DURING CRUISE FLIGHT

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Weather effects on aircraft wake turbulence in the terminal area are a current topic of international research. Due to recent reductions in vertical aircraft spacing over the north Atlantic ocean, there is increasing international interest in the effects of wake turbulence during cruise operations. This paper presents an analytical study of the effects of weather and aircraft size on the potential for wake turbulence in cruise. A simple model of wake motion and decay is used to estimate the effects of winds, atmospheric turbulence, and temperature lapse rate on the maximum distance which a wake might descend. An estimate is also provided as to whether or not the wake remains coherent or descends as a series of crude rings due to the Crow Instability. The wing span of the generating aircraft is show to be a critical parameter in addition to the weather.

Impact of Adverse Weather on Major US Airports

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Adverse terminal weather is of particular concern at major US airports due to the very high traffic volume, the frequency of convective weather, air traffic operational procedures and airline scheduling procedures. This paper summarizes lessons learned in 10 years of experimental terminal weather information system operations at major US airports, including Dallas/Ft. Worth, Orlando, Memphis, Kansas City, Denver and San Francisco. We review first the implications of the overall air traffic management philosophy used in the US in creating sensitivity to adverse terminal weather. Recent results in the area of safety (especially windshear, gravity waves, downbursts, and CAT near storms) are described, including statistics on the relationship between microbursts and days with thunderstorms. We then discuss the impact of convective weather and low ceiling/visibility on delays and operational efficiency. It is shown that a significant fraction of the delay is "avoidable," given better weather and air traffic management decision support tools. The paper concludes with a summary of implications of the US experience for European airports.

PARTICIPATION OF METEO-FRANCE IN WAKE VORTICES STUDIES

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In order to reduce aircraft separation standards defined by ICAO, Meteo-France has developed different wake vortices studies, as requested by the STNA (« Service Technique de la Navigation Aérienne »). In the first study, the effect of crosswind on wake vortices trajectory is analysed by using the VORTEX model, developed by CERFACS (« Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique »). This model allows real-time evaluation of hazards associated with the wake vortices. The work has led to the definition of crosswind classes related to hazard duration, which corresponds to the time the two vortices stay inside the safety corridor (defined as the range ± 45 m from the runway axis). These classes depend on the number of runways and their distance. Regarding the configuration « separation of 3NM on independant runway », two classes of crosswind are needed: smaller than 3 $m.s^{-1}$ and larger or equal to 3 $m.s^{-1}$. The second study analyses the evolution of wake vortices at small scale in 2D by using the French Méso-NH model, an atmospheric simulation code developed in cooperation between Meteo-France and the CNRS (« Centre National de Recherche Scientifique »). This model is initialised with the Idaho Falls experiment data. Different crosswind, stratification and wind profile are simulated for stable and mixed convective boundary layer. The work on the crosswind leads to about the same classes as with the VORTEX model. The VORTEX model could be improved in a further step by using the results on stratification and windshear.

WEATHER IMPACT ON THE AIR TRAFFIC IN THE THREE AIRPORTS OF GALICIA (SPAIN)

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Galicia is the Spanish region placed in the Northwest of the Iberian Peninsula. There are three international airports in the region placed in Vigo, Santiago and La Coruña. The aim of this study is to know the meteorological patterns that have produced problems in their air traffic in the last five years, to classify these patterns, to evaluate the cost/pattern for different air companies and to study the benefits that an improvement in the nowcasting could have produced.

THE PREDICTION OF VERY SHORT PERIOD CROSSWIND SPEED USING STATISTICAL TECHNIQUES.

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Any future wake vortex advisory system needs to have the capability to predict the strength of the crosswinds affecting aircraft in the vicinity of the runway. Wind measurements are routinely taken at all airports and these measurements are available to the pilot through air traffic control. This is problematic since it is unlikely that the measured wind speed would be appropriate to the precise time and location of the aircraft on either final approach or after take-off.

It is known that the use of persistence gives a reasonable forecast of wind speed over short time periods or short distances although the use of predictive statistical techniques can reduce forecast errors quite markedly.

This paper describes the use of various techniques for crosswind prediction as applied to a large sample of one-minute reading taken at Memphis airport during 1995. Results are presented showing the improvements in forecast accuracy that can be gained through the use of these techniques.

VORTEX WAKE MEASUREMENT TEST RUN FACILITY SCHIPHOL

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The flow field downstream of the Test Run Facility at Schiphol Airport was measured to obtain detailed and quantitative data on the vortiex wake. It was found that this wake was characterised by two strong vortices and a large velocity defect. The facility, which consisted of 16 m high walls, is located at 330 m sideways from the eastern threshold of runway 27. Under quartering headwind-conditions the wake of the building crosses the approach path. The tests were initiated as a result of pilots reporting not only elevated turbulence levels but occasionly also speed loss and aircraft bank. As these perturbations were experienced during the final approach phase, restrictions were issued on the use of runway 27 under certain wind conditions. The measurements, directed towards reducing the wake-disturbance, were performed in the DNW-LST 3*2.25 m². The downstream development of the flow was measured by means of a scanning 5-hole tube rake, enabling a rapid measurement of the velocity vector field in a cross-section behind the model. Turbulence data were also obtained at some positions. It was found that the concentrated wake was lifted by the action of the vortices, although the latter were found to decay rather quickly, probably due to dissipative action of the viscous wake. The results have been used as input to some first flight-simulator studies. These suggested that the perturbations to the aircraft motion, as experienced in practice were caused primarily by the velocity defect in the viscous wake and not by the vortices. The study lead to a lowering of the walls from 16 to 6 m.

OBSERVATIONS OF AIRCRAFT ICING AND SUPERCOOLED LARGE DROPS

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During the EURICE flight campaign March 1997 a DLR DO-228 research aircraft made five flights over Southern Germany in supercooled clouds. The aircraft was equipped with optical cloud probes (OAP 2DC, FSSP 100, FSSP 300), a LWC probe, a temperature sensor and an icing cylinder with video documentation. The measurements took place in mixed-phase stratus clouds and stratus with embedded convection. Cloud top temperature was at about -5° C. Maximum icing rates of 3.5 mm/min together with drops in the size range 50 - 200 µm (SLD) were found frequently and on spatial scales ranging between several hundred meters and several kilometres. Ground-based radar observations show clearly that these SLD events occurred whenever the aircraft penetrated one of the embedded convective cells. SLD were found at all heights but seemed to be more frequent near cloud top where also maximum LWC values were found. A physical picture of the SLD mechanism will be developed and implications for the aircraft icing problem will be discussed. A video clip shows the growth behaviour during SLD events and for standard icing.

Analysis of Stalled Vortices at DFW Airport

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Separation standards for final approach must account for the possibility that a wake vortex generated by a preceding aircraft may, because of interaction with the ground and the ambient crosswind, stall in the glide path. A ground-based array of anemometers was used extensively in the 1970s to detect stalled vortices. An array also gives measurements of the ambient wind close to the location where the vortices lateral motion is measured. Data recently collected at Dallas-Ft. Worth Airport are analyzed and compared to the 1970s results. The analysis concentrates on the arrivals when atmospheric turbulence was low to optimize the vortex detection and to select conditions when long vortex lifetimes can be expected.

AIRCRAFT WAKE VORTEX CHARACTERISTICS IN THE STABLY STRATIFIED ATMOSPHERE

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Aircraft wake vortices (WVs) may exert a serious danger on a following aircraft if the separation between the leading and following aircraft is not sufficient. In view of the expected growth of air traffic, increasing demands on the capacity and safety of international airports have to be faced. A promising approach to increase the capacity of airports is to model the temporal evolution of WVs in order to forecast their lifespan.

It is meanwhile generally accepted that meteorological conditions such as turbulence, stratification and shear dominantly determine the development of WVs. We focus on the impact of the stably stratified atmosphere, an issue which has been discussed controversly since years. Based on 2-D and large eddy simulations as well as simple vortex element methods the behaviour of WVs is analysed. Depending on the degree of stratification we observe both an accelerated and a decelerated descent of WVs. Both effects are explained by the interaction of the WV's flowfield with vorticity produced due to baroclinicity.

SIMULATION INVESTIGATIONS INTO AIRBORNE REACTIVE AND FORWARD LOOKING WINDSHEAR DETECTION SYSTEMS.

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The paper to be presented outlines the results of the Flight Mechanics 5[th] Action Group of the Group for Aeronautical Research and Technology in EURope (GARTEUR). The aim was to have a better understanding of the behaviour of a transport aircraft under windshear conditions, and the improvement in flight safety that can be achieved by using an airborne windshear detection system. Some results from an inquiry held amongst European airlines to inventory their experience with occurrences of windshear events are reported. A complete non-linear numerical simulation was set up in order to analyse the aircraft response during windshear encounters at approach/landing and take-off. The generic aircraft was assumed to be equipped with a fully automated flight guidance coupled to an airborne windshear detection system such as reactive and forward looking system (FLS). The windshear scenarios were selected from existing models providing realistic wind situations. The investigated atmospheric threats were the downburst/microburst situation and the low-level jet. The simulation environment was designed to perform a parametric study on various factors such as specific characteristics of a forward looking windshear detection system of the Doppler-lidar type, severity factors, intensity and location of windshear. Some basic results are presented to show the advantage of a forward looking windshear detection system, compared to a reactive system. With an advance alert-time of more than 20 s the fully automated system has the potential to improve aircraft safety, even in case of extreme windshear conditions. But the most promising concept seems to be a combined use of reactive and FLS.

WAKE VORTEX HAZARD DETECTION DOPPLER LIDAR

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The performance of an airborne, wake vortex detection system is investigated by simulation. The proposed detection system uses a forward looking, pulsed Doppler Lidar to interrogate the intended flight path of the aircraft. It aims to give advance warning of any hazardous wake vortices, generated by preceding aircraft, that enter the aircraft's intended airspace. Any Doppler system is only capable of resolving velocities in the direction of the emitted wave. Thus, the proposed system aims to detect hazardous wake vortices based on axial characteristics.

Realistic wake vortices are simulated in a convective atmospheric boundary layer using a three-dimensional Large Eddy Simulation model. The simulation is initialised with data collected during trials made at Idaho Falls by the Federal Aviation Authority in 1990. The evolution of the vortices in characteristic atmospheric conditions is then calculated. At discrete stages in the evolution, the computed flow field is applied to the Lidar system simulator. The Lidar system simulator models the shot noise limited Lidar, the atmosphere and the signal processing, outputting the set of line of sight velocities that would be measured by a Doppler Lidar interrogating the given flow field. Pattern recognition techniques are used to detect any vortices. At each stage the hazard posed by any vortex in the flow field is estimated by calculating the rolling moment that it would affect on an encountering aircraft. If this rolling moment is of the same order as the rolling-moment capability of a commercial transport aircraft, then it is classified as a hazardous vortex. This paper aims to demonstrate that all such hazardous vortices can be detected using the proposed Lidar system.

IN-FLIGHT ICING CLOUD MEASUREMENTS BY AN AIRBORNE DROPLET ANALYSER

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CIRA experimental involvement in EURICE project for severe icing conditions research in the atmosphere concerned the participation to the flight test campaign conducted in March 1997 in The Netherlands on NLR research aircraft. CIRA contributed to the flight tests with the utilisation of an optical probe based on Phase Doppler measurement technique for the individuation of droplets diameter distribution in the clouds. So on an Airborne Droplet Analyser (ADA) has been developed and installed on NLR aircraft with the main aim to be able to detect droplets in a range between a few until 600 and more microns. During three flights the probe acquired droplets of different diameters with presence of sparse large droplets; diameter distributions have been correlated with altitude and air static temperature during each of the three flights. Median Volume Diameters and Liquid Water Contents have been calculated for shorter time interval when the cloud characteristics and the data rate allowed to have a consistent number of droplets acquired. The results obtained have been analysed in order to compare data to FAR 25 App. C icing certification requirements and to foresee tests conditions for performance degradation research in icing wind tunnel facilities.

MORE INSIGHT INTO AIRCRAFT WAKE VORTICES BY MEANS OF GROUND-BASED CW DOPPLER LIDAR

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Aircraft wake vortices are presenting a potential hazard to other aircraft following closely behind. This is not only a safety problem but also a capacity problem at major airports. Several approaches are under investigation: A reduction of the presently binding separation distances can be achieved by long-range airfield systems or forward-looking on-board sensors for wake-vortex detection and warning. In the design phase of new aircraft types, mechanical features for vortex alleviation can be taken into account. Supposition for these approaches is the precise knowledge of the vortex properties and their temporal behaviour. At DLR, a cw Doppler Lidar has been developed for boundary layer wind measurements. This system is also used for the investigation of vortex properties, like velocity distribution, circulation, transport in ground influence and decay. During several field experiments, the signatures of a large variety of aircraft types have been acquired covering the bandwidth from small business to large commercial aircraft. Experimental data will be presented, including data of scarcely investigated vortices like those being generated by fighter-type aircraft and by helicopters. The relationship to aircraft parameters and to the atmospheric environment will be considered.

SUPERCOOLED LARGE DROPLETS IN ICING CONDITIONS

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In March 1997 NLR investigated the icing atmosphere for aircraft by flying with an instrumented research aircraft through clouds. Liquid water content, droplet diameter distributions and air temperature were measured. Large droplets were found in air masses with a limited extent. Results from the measurement campaign are presented. Implications of ice accretion on helicopters and fixed-wing aircraft due to large droplets are discussed. The investigations were part of the project EURICE, a co-operation between aircraft manufacturers, research institutes, civil aviation authorities and universities.

COMPARISON OF ASR WEATHER CHANNEL ECHO AND 3 D LIGHTNING OBSERVATIONS IN FLORIDA STORMS

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Precipitation radar echo of a Florida storm is provided by the weather channel of an Airport Surveyance Radar. ASR delivers a vertical integrated echo of precipitations. The 2D storm cells described by this radar are compared with 3D lightning location provided by a high resolution VHF interferometer. We discuss how interpretation of informations on storms from a simple weather radar device can be improved by a detailed description of the lightning activity. Application of this concept to Air Traffic Management support is also discuss.

AVIATION WEATHER IMPACTS ON AIR TRAFFIC MANAGEMENT

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Weather has a major impact on the capacity, efficiency, and safety of the air traffic management (ATM) system. Runway acceptance rates and other capacity metrics are reduced in instrument meteorological conditions. According to some studies, 40-65 percent of delays that impact U.S. domestic airlines are caused by adverse weather, at annual direct costs ranging from $4-5B per year. Passengers are inconvenienced by flight delays and cancellations or diversions due to weather, and are uncomfortable or may even be injured when turbulence is encountered during a flight. The expected future growth in air traffic will only exacerbate these conditions, imposing constraints on the ability of the industry to meet growing demand while improving safety and efficiency. The capability to observe, analyze, forecast, and disseminate weather information can be improved by recent technical developments, but the air transport industry lacks a consistent understanding of how to evaluate and use these new capabilities in the most beneficial way. The relative value of different types of weather products, the timeliness of their delivery, knowledge about the users and providers of aviation weather information, and other factors need to be understood to ensure that investment in technology development and operational systems provides optimum value. In this paper we present some of the findings from a study we are conducting to develop technical and business-relevant information on the impacts of weather on the ATM system, and on the role of weather information in emerging communications, navigation, and surveillance (CNS) technologies. We describe user requirements for aviation weather information, explain where operational deficiencies exist in the aviation weather system, and evaluate the impacts that emerging aviation weather technologies may have on improving efficiency and increasing capacity in the ATM system.

Developing the Real Time Verification System to Support Aviation Forecasting and Product Development

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This presentation will describe the Real-Time Verification System (RTVS) that NOAA Forecast Systems Laboratory (FSL) is developing to support aviation forecasting and product development. Verification of products (e.g., AIRMETs and SIGMETs) and the "guidance" forecasters use to generate those products is very important to the safety and efficiency of the airspace system.

FSL recently implemented the initial version of the RTVS at the National Weather Service (NWS) Aviation Weather Center (AWC). The version included capability to assess the quality of AIRMETs (icing, turbulence, and IFR conditions) and algorithms that generate forecasts of icing and turbulence. Based on feedback we gathered from AWC and the results of a previous assessment of requirements, we envision that the end-state RTVS will enable: 1) developers to assess the quality of algorithms for forecasting variables such as icing, thunderstorms, and turbulence; 2) program leaders and managers to assess the quality of algorithms and end-user products; and 3) aviation forecasters to assess the quality of the "guidance" available to help generate products for end-users.

FORECASTING TURBULENCE IN THE UPPER TROPOSPHERE

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At the Forecast Systems Laboratory (FSL), research is now in progress to develop and test diagnostic and prognostic turbulence forecasting algorithms to provide guidance for the aviation community. With the advent of reporting objective turbulence observations from aircraft, such as the vertical accelerometer and the in-situ dissipation rate data, it has been possible to begin development and verification of turbulence forecasting formulations that estimate, in a more physical way, those turbulence events that are dangerous to general and commercial aviation. A diagnostic algorithm (DTF5.0) has been developed to forecast turbulence from three sources: shear instabilities (in the boundary layer, and around upper fronts and jets), gravity wave breaking (e.g., mountain waves), and convection-related turbulence. Using the vertical accelerometer data, it has been possible to define a turbulence threshold, because approximately 90% of these reports correspond to no-turbulence, whereas >90% of the voice pilot reports (pireps) related the occurrence of turbulence. Verification statistics for the three components of DTF5.0 will be shown, including a discussion of seasonal and geographic dependencies. Results using the subjective and uncalibrated pireps will be contrasted with those from the objective measures (vertical accelerometer data and dissipation rate). Comparisons with a two-year set of statistics based on pireps for an earlier version of the diagnostic (DTF3.0) will also be made.

EFFECTS OF ATMOSPHERIC CONDITIONS AND GROUND PROXIMITY ON THE DYNAMICS OF AIRCRAFT WAKE VORTICES: A STUDY OF THE 1994-95 MEMPHIS FIELD MEASUREMENTS

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This paper studies aircraft wake data acquired by the MIT Lincoln laboratory and NASA Langley Research Center at the Memphis, TN international airport during December 1994 and August 1995. The objective is to identify the dominant mechanisms affecting the transport and decay of aircraft wake vortices. Specifically, the effects of atmospheric stratification, wind shear, atmospheric turbulence and ground proximity on the far-wake development are examined. The wake-vortex trajectories are observed to closely follow the ideal descent path under calm and near-neutral atmospheric conditions and away from the ground. Increased variability in the vertical wake trajectory is noted under high ambient turbulence (normalized turbulence levels in excess of 0.5) with observations of descending as well as rising vortices for the same turbulence energy. Interaction of the wake vortices with nonuniform ambient vorticity associated with a ground-jet crosswind profile is observed to arrest their vertical descent leading to a rebound. No discernible changes are observed in wake-vortex transport and decay over a normalized Brunt-Vaisala frequency range of 0.2 to 0.5. Wake-vortex rebound due to viscous ground interaction is observed to occur about one time unit after the arrest of the initial vertical descent. For wake vortices generated sufficiently close to the ground, the rebound is immediate. An effect of stratification on the rebound process is not observed over a range of normalized Brunt-Vaisala frequencies of 0.07 to 0.35. Furthermore, neither winds aligned with the wake axis nor wind shear in this direction appear to influence the rebound process.

ANALYTICAL AND NUMERICAL INVESTIGATIONS OF THE AIRCRAFT CONDENSING VORTEX WAKE

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The interest to the processes of atmosphere vapour condensation, particle creation and their subsequent agglomeration in the aircraft vortex wake is provided by the actual environmental problems. The aim of these investigations is to obtain simple precise formulae for the droplet and crystals concentration and mass fraction for certain physical regions and to compare them with the results of numerical research which have been carrying out parallel with the first. Condensation and aglomeration are considered on the "background" of the gasdynamical field of the vortices and jet of aircraft. Analytical approach include finding of self-similar solutions and the disturbances theory. In order to create a real model of a gas velocity field in the vortex wake a various turbulent models are used. They include also a self- similar low for the turbulent velocity coefficient. In conclusion an optical properties of aircraft condensing vortex wake are researched.
The work is supported by International Science and Technology Center, Projects #200, #1018.

INQUIRY INTO THE GROUND ATC/ATM REQUIREMENTS FOR METEOROLOGICAL DATA

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The aim of this inquiry is to access the actual and future needs for meterological information in the domain of ATC. The assessment has been achieved by sending a questionnaire to 24 European and non-European CAA organisations but also airports and Eurocontrol. This questionnaire was designed to find out the needs for new meteorological facilities as supplementary of information to french CENA inquiry which dealt with the needs of the controllers for meteorological information. This inquiry has tackled different thematics : data quality. meteorological phenomena. man machine interface. simulations and recording. new capabilities. prospectives thematics. ... .Answers analysis has revealed expectation for a better weather information. centralized on a common interface and particularly for storm forecasting visualization in order to increase safety. It appears that En-route flying requires turbulences and icing danger estimation. For accident/incident investigation. they asked for ability to exploit weather data recording. It appears that detection and tracking of thunderstorms requires a forecast period from 15 minutes to 3 hours. This inquiry has been funded by European Communauty for the project named 4MIDaBLE (« 4D Meteorological Information Data Base Linked across Europe ») in a consortium including Meteo France. UK Met Office. Sofreavia and Thomson-CSF which was responsible of the study of meteorological requirements for Air Traffic Management. We will present its results in this paper.

STORM FORECASTING WITH RADAR IMAGE PROCESSING BASED ON MODEL-CONSTRAINED & GEODESIC ACTIVE CONTOURS

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The aim of this study is to perform a short term nowcasting of storm evolution (shape and position). Storms can be tracked by means of adapted algorithms based on new techniques such as geodesic active contours (front propagation) combined with (affine)model-constrained active contour for deformation prediction and topological change adaptation. The efficiency of our methods will be demonstrated on meteorological radar images. This application has one objective : civil traffic regulation according to severe atmospheric phenomenon. These works have been included in the European 4DMIDaBLE project. We will describe two main image procedures used for thunderstorm clouds tracking : geodesic active contours based on Hamilton-Jacobi formulation of curve evolving, and model-constrained active contour based on Euler-Lagrange formulation with affine deformable model. Finally, we will expose the new associate algorithmic chain for storm clouds detection and tracking, that manages topological changes and allows short term forecasting from 5 to 20 minutes of clouds deformation. The efficiency of our methods will be demonstrated on multisensor atmospheric images : radar (meteorological radar, meteo. channel of Airport Approach Radar), VHF interferometer (SAFIR) and satellite images (Meteosat). Correlation between SAFIR and Radar data has been demonstrated on real records.

INVESTIGATION INTO LIGHTNING STRIKES TO HELICOPTERS OPERATING OVER THE NORTH SEA

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A preliminary study to investigate lightning strikes to helicopters operating over the North Sea showed that on a significant number of the events the pilots reported no previous lightning activity to be present. This led to the hypothesis that the helicopter triggered the lightning strike as a result of its presence at that point in space and time. This study set out to investigate the meteorological conditions surrounding the lightning strikes. Eleven incidents dating back to 1992, have been studied. Data has been extracted from Met. Office archives for the dates and times of the incidents. The analysis of the synoptic data (synoptic charts and satellite pictures) showed that in all eleven cases being studied, cumulonimbus (Cb) clouds were in the vicinity. This information is not strictly in contradiction to the previous study in that the Cbs may not have started producing lightning until the helicopter flew into it. It is true to say, however, that large charged regions will have developed within these Cbs.
A null data set was generated from dates, times and locations when similar Cb clouds were present alongside helicopters and a lightning strike didn't occur. The meteorological data from this null data set was then compared with the meteorological data from the eleven strike incidents that are being studied in depth.

ST17

A SUCCESS STORY BETWEEN NAV CANADA (Nation's provider of civil air navigation services) AND ENVIRONMENT CANADA.

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With the increase in the number of flights and the need to provide cost efficient weather services, the WWW has revolutionized NAV CANADA ' s means of providing this service. The level of popularity has surpassed expectations. The main goal was to increase the quality of service to pilots without an increase in operational costs. The option that was put to test : give the users the opportunity to brief themselves before contacting the Flight Service Station (FSS). As a result, consultation time has diminished and become more efficient. In this instance, the use of the Internet has succeeded in uniting major premises, bringing together data accuracy, efficient access and packaging information according to the users needs. Now both the pilot and the FSS briefer possess the crucial material required to conduct effective and safer exchange of information. The pilots'imputability has thus been raised considerably. The poster will display all aspects of this success story about providing better services to an increasing number of users without raising operational costs.

INFLUENCE OF WIND PREDICTION ON THE CAPACITY OF A TIME-BASED ATM SYSTEM

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With the fast growing air-traffic and stringent environmental regulations, the Air Traffic Management (ATM) system faces new demands. According to EUROCONTROL studies, a time-based ATM system could satisfy these demands. Within a time-based environment, the accuracy of the current arrival times prediction has to be improved in order to improve the capacity whilst maintaining the same level of safety (separation). This paper presents the results of a small scale experiment which investigated the influence of the current wind prediction on the accuracy of ground based arrival time prediction. Forty-two inbound flights to Schiphol Airport (The Netherlands) were executed under the condition of a constant speed and a continuous descent from an instructed top of descent (TOD). Arrival times were predicted with an algorithm using, amongst others, the speed and TOD instructions and the wind information. Arrival times calculated with the actual winds (as observed onboard the participating aircraft) instead of the predicted winds, showed an improvement in accuracy of approximately one-third. This indicates that under the condition of a constant speed and a continuous descent from an instructed TOD, the accuracy of the wind prediction has a large influence on the accuracy of the arrival times. From this experiment, it can be deduced that improved wind prediction is required to improve the capacity of a time-base ATM system. Further research should therefore focus on improving the wind prediction e.g. by using a data-link between the aircraft and the ground. With the data-link, meteorological information observed onboard the aircraft could be transferred to the ground, using the aircraft as a weather station.

USER SENSITIVITY TO CEILING AND VISIBILITY AND ITS INFLUENCE ON TERMINAL FORECAST VERIFICATION

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The paper describes two distinct activities:
a) For transport aviation users sensitivity is measured by the cost to the user of a wrong forecast. The costs incurred to airlines in the use of optimistic and pessimistic forecasts of ceiling and visibility at the destination and diversion airports usually occur at the planning stage with respect to fuel loading procedures. The actual cost that results is affected by the decisions made by the captain of the aircraft at the various stages of the flight. For general aviation, although the sensitivity to particular meteorological parameters is quantified, it is not possible to derive an economic cost/benefit. The sensitivity is derived through questionnaires to GA pilots, flying clubs and flight briefing units.
b) Verification of Terminal Aerodrome Forecasts (TAFs) is not straightforward owing to the complex format in which the forecasts are given. A brief discussion is given showing that assumptions have to be made as to forecast interpretation before any verification scheme can be derived. An appropriate scheme is then selected that caters for user sensitivity.
Results of these two activities are combined to give a measure of the cost of inaccurate forecasts at a particular site. This cost is then compared with the costs incurred using a perfect forecast.

THEORICAL STUDY OF THE DRIZZLE FORMATION BY CO-ALESCENCE

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Supercooled drizzle is a meteorological hazard that can have fatal consequence for small airplanes because ice accretion can occur aft the protection area. The growing process for drizzle that cannot be explained by water phase change can be due to droplet coalescence. Especially, in the case of non convective clouds, the drizzle growth was observed to be related to a wind shear at the top of the cloud. We describe the evolution of the drop spectrum in term of a stochastic equation. The collision rate is determined for the shear turbulence flow. The hydrodynamic interactions and the van der Waals forces are taken into account. The stochastic equation is solved by the Kovetz-Olund method by using a quadratic finite element interpolation. The time necessary to form large droplets is calculated as the time of increase of the median volumic diameter. This time is compared with experimental observations.

NEW METEOROLOGICAL DATA FUSION CONCEPTS FOR STORM NOWCASTING APPLIED TO ATC

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The objective of the development of new concepts for storm nowcasting is to provide in real-time to a meteorological data end-user such as the air-traffic controler a synthetic information about the storm evolutions which shall be sufficiently detailed and accurate to enable immediate identification and anticipation of hazardous phenomena caused by thunderstorms.
The synthetic information is based on the fusion of weather radar data and SAFIR total lightning activity data ; it benefits from the complementarity of these two informations for the identification of storm phases such as highly convective growth phase which perturbs the en-route traffic or intense precipitation downburst phase which can be hazardous in the terminal area.
Data fusion is performed on a pixel by pixel (1 km²) basis, using a two dimensional fusion matrix combining radar reflectivity and total lightning density, by setting classes directly related to the phase and intensity of the storm activity. It provides a synthetic map of hazardous storm areas, and gives to the end-users an information which is no longer a complex set of weather information, but represents the different cases of potential perturbation of the air traffic, and thus can be used for decision aid.
This approach shall be illustrated with air-traffic situations during the presentation.
The basic concepts were developed by Dimensions within the European project 4Midable (4D Meteorological Information Data Bases linked across Europe) funded by DGVII (Transports) of the European Union.

Developing Grid Interaction and Product Generation Tools for NWS Aviation Forecasters

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This presentation will describe the effort by NOAA Forecast Systems Laboratory (FSL) to develop software tools that will enable National Weather Service (NWS) aviation forecasters to efficiently add value to (edit) high-resolution gridded Aviation Impact Variables (AIV) generated automatically by forecast models and post-processing algorithms. Examples of AIVs are icing, turbulence and clouds. The software tools will also enable graphical and text products to be efficiently generated from those value-added AIVs. The value-added AIVs, which will be made available to the aviation community via the NWS Aviation Digital Data Service (ADDS) and NOAAport, will also be appropriate for supporting FAA automation systems and free flight.

We are developing the software tools to run within the FX-Advanced meteorological workstation which is the basis of the National Weather Service (NWS) Advanced Weather Interactive Processing System (AWIPS). Initial versions of the tools are being evaluated at the NWS Aviation Weather Center in Kansas City, Missouri, USA.

GIANT SUPERCOOLED DROPS IN Cb

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During the summer of 1997 a Campaign was carried out in the Ebro Valley (Spain) to measure certain characteristics of storm cells. Three kinds of platform were used for observation: the Meteosat and NOAA satellite, a C-212 equipped with various kinds of sonde for measuring cloud microphysics, and, finally, a meteorological radar (Band C) with the TITAN and RDAS systems for data acquisition and processing. The study zone was a circular area of about 160 km in radius, centering on the city of Zaragoza. The proximity of the Mediterranean means that in conditions of thermodynamic instability, moisture spreads very quickly through the Valley.

A flight made on the 16 July 1997 was selected, because drops of this kind appeared in the interior of a storm cell, carried upwards by a strong ascending current (a maximum updraft >20 m/s was recorded). It was possible to see signs of ice-forming on the aircraft. The C-212 penetrated the cell from the right-hand southern. The temperature at the cloud base was +9°C and the flight altitude was at -2°C. The presence of a gigantic drop can be appreciated, which, if perfectly spherical, would have a diameter of 4637.4 um. On average, in the region where the increase in the volume of liquid water is most noticeable, the drops have a diameter of 715.5 um, which indicates that the small drops are scarce. After crossing various sections of the cloud, it was possible to see signs of ice-forming on the skin of the aircraft.

AN OVERVIEW OF PROJECT SOCRATES

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Project SOCRATES is a research and development project aimed at addressing air safety and airport productivity through application of advanced technologies previously investigated for the U.S. Department of Defense. The basic premise is remote detection and localization of acoustic signatures from man-made and natural atmospheric turbulence. An acousto-optic technology is used to sense low frequency sound that has propagated from the atmospheric hazard to an optical sensing beam. This presentation will describe the basic sensing concept as well as the current effort to demonstrate concept feasibility for detection of sound generated by aircraft wake vortices. Results from measurements taken at JFK airport will be presented. Subsequent efforts to develop an array of sensors and the processing to achieve interference reduction and sound source localization will also be described. The long term view is to integrate this novel sensing technology with appropriate air safety systems to enhance overall capability and effectiveness.

PROCEDURE FOR SCIENTIFIC FLIGHTS IN Cb

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Within the EURICE Program, in the Ebro valley an experimental procedure has been developed for the characterization of severe convective phenomena. Among the actions which have been carried out in the summer of 1997 we can point out the elaboration of a manual for flights inside the storm cells, to enable the penetration into those zones which are scientifically interesting for storms, minimizing the flights risks. The information provided by those flights has allowed us to progress in the knowledge of the characteristics of storms in a certain area of Spain, the Ebro valley, which is overflown by one of the most widely used air corridors in Europe.

DIAGNOSIS OF ICING AND NOWCASTING FOR AVIATION

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DIANA, a system for Diagnosing Icing conditions for Aircraft and Nowcasting for Aviation is under development at DLR in collaboration with the German Weather Service (DWD). Multiple data sources like conventional data, mesoscale model output, satellite and radar data together with pilot reports will be used to detect and nowcast regions where so-called "supercooled large drops" (SLDs) are likely to occur. SLDs are cloud droplets in the size range of 50 to 500 µm which can lead to rapid accumulation of ice on wings and tailplane if encountered by aircraft. As SLDs cannot be explicitly forecast, various icing algorithms implemented into the PennState/NCAR model MM5 provide a first guess of these regions. In a step by step procedure these generally overforecasted regions with icing conditions will be truncated by use of the AVHRR Processing scheme Over cLouds, Land and Ocean (APOLLO) developed by DLR. Radar measurements can be used to identify convective areas and freezing rain. Pilot reports will be used both for verification and improvement of the icing routines. Finally, after a testing periode, DIANA will be implemented into the routine aviation hazard warning service of the DWD.

AN AUTOMATED SCHEME FOR PREDICTING MOUNTAIN WAVE INDUCED TURBULENCE FOR CIVIL AVIATION

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Clear air turbulence (CAT) is a major meteorological hazard to aircraft, and is currently difficult to forecast with reliable accuracy. Apart from frontal effects and jet streams, the principle cause of CAT is mountain-induced gravity waves. These form as a result of stably stratified flow over mountainous terrain, and propagate upwards through the atmosphere. The turbulence resulting from breaking gravity waves constitutes a significant hazard to civil air traffic at cruising heights, particularly over midlatitude ranges in wintertime.

This report investigates the potential of gravity wave drag parameters from the UM to be used as an objective indication of mountain wave turbulence (MWT). Three case studies over the Alps are presented, where model data is compared with actual turbulence reports from civil aircraft. The three cases represent contrasting meteorological conditions over the same area.

The results show that the magnitude of the gravity wave stress vector is related to the frequency of positive turbulence reports, although more data is needed to quantify this further. These results will be used along with further studies to develop an automated operational system to predict areas and associated risk of MWT encounters at cruising altitudes across the globe.

ETWIRL: A NEW PAN-EUROPEAN WAKE VORTEX REPORTING SYSTEM AND DATABASE

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Increasing demands on European airport capacity has recently brought the issue of wake vortex hazards to the forefront of aviation research. However, current wake vortex separation rules take no account of the effects of meteorological conditions. With sufficient understanding of these effects, the potential to decrease separations under favourable meteorological conditions could be realised without compromising safety standards.

The European Commission has recently contracted aviation specialists RED Scientific Ltd. along with the UK Met. Office to implement a Europe-wide wake vortex incident reporting system, utilising both automatic and human data sources. The project, named ETWIRL (European Turbulent Wake Incident Reporting Log), will run for two years, and will develop a database of wake vortex encounters at European terminals along with comprehensive meteorological data.

This paper describes the expected content of the database together with a discussion about potential methods of data dissemination to interested parties. Confidentiality issues and the future role of the database will also be discussed.

ON THE SOUND GENERATED BY AIRCRAFT TRAILING VORTICES: A DESCRIPTION OF THE PROJECT SOCRATES THEORY AND MODELING EFFORT

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Results are presented of the Project SOCRATES Theory and Modeling study concerning the acoustic signature of aircraft wake vortices. The paper, which is an account of a work in progress, will focus on the examination of the physical mechanisms responsible for low frequency vortex-generated sound using a combination of analytical, computational and experimental methods. A lagrangian vorticity collocation method is used to compute the dynamics of columnar trailing vortices and Powell's form of Lighthill's acoustic analogy is used to compute the resulting sound field. Analytical results for a few canonical problems, such as the sound radiated by small amplitude core vibrations of infinite columnar vortices and vortex rings, are used to validate the numerical calculation of the acoustic field. Results of computational simulations will be shown for several model problems. Of particular interest for the wake-vortex problem is the sound field radiated by columnar vortices with periodic wrapped vortex rings which are known to form when strong coherent vortex structures interact with the relatively weak small scale structures embedded in the ambient turbulence. That interaction is expected to be a dominant sound radiating mechanism for trailing wake vortices. Computational and measured sound field characteristics will be compared in an attempt to support or refute that supposition.

COMPUTATION OF WIND EFFECTS IN THE WAKE OF BUILDINGS CLOSE TO A RUNWAY

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Large buildings close to a runway may cause wake disturbances that can influence landing and take–of conditions significantly. This is estimated by numerical flow simulations. A 3D finite element formulation is applied in the numerical model. The model is based on the Reynolds equations with a modified two–layer (K, ϵ) closure. Special wall elements are applied to implement the wall boundary conditions accurately. Realizations of the flow field along the runway are obtained by Monte Carlo simulations. Test results are provided by application to flow around a cube, with comparison to experimental and other numerical data.

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An Interactive Aviation Weather Database (AWeD)

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A database of gridded aviation-impact variables has been created to be the core component of an aviation weather display system designed to be used as a briefing-aid tool. In its current state it includes: temperatures, winds, icing, turbulence, cloud fraction, relative humidity, vertical velocity, tropopause pressure and temperature, freezing level, total cloud cover, instantaneous precipitation rate at the surface and station pressure. The content of the database is generated from the operational Canadian Regional model outputs on a 35 km horizontal resolution grid, at 41 flight levels from the surface up to 40 000 feet, and at every 3 hours from zero- to 48-h projection time. The database is updated twice per day (00 and 12 UTC) in real time. The domain of the database covers all of Canada, adjacent waters and a significant portion of the United States. The current icing algorithm used is based on supercooled liquid water content forecast by the driving model. The turbulence algorithm is based on the deformation vertical shear index taking into account horizontal and vertical wind shear. Different other algorithms for icing and turbulence are also being tested. METARs and TAFs are available through the database and can be displayed in graphical format. The database is made accessible on network through a JAVA based graphical users interface. This application allows the users to enter flight parameters, such as departure and arrival airports, check points along the planned route, estimated elapse time of the flight and flight level. Series of meteorological products, all tailored to each particular flight, in plan view and vertical cross-section along the route, can then be generated and downloaded to the users. The system is thus fully interactive. A verification system is also under development as part of the database, in order to assess the reliability and performance of the different aviation impact variable algorithms.

INVESTIGATION OF A GRAPHICAL AREA FORECAST IN CANADA

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The Atmospheric Environment Branch of Environment Canada is examining a graphical area forecast (GFA) to communicate enroute aviation weather more effectively and precisely. The worded area forecast (FA) has been the primary source of enroute weather for general aviation in Canada and the US for over 50 years. The restrictions of text are often an impediment to effectively communicating the evolution and structure of clouds and weather. A graphical replacement overcomes many of these limitations and has become feasible with high speed telecommunications and powerful, affordable computers. Potential users have responded favorably and several formats have been demonstrated. The aviation community in Canada is currently being consulted to address outstanding issues of content, readability and geographical domain. The simplest solution is a computer drawing package to generate consistent readable products. A far more exciting possibility is to store the forecast information in a geo-referenced database from which a limitless number of information subsets can be extracted. These could be varying geographical domains or collections of weather elements at any point in time, displayed in two or three dimensional views. . It is also possible to automate production of corresponding worded FA,s., A database system can also facilitate more complete integration of observational data and numerical guidance into forecast production.

OA23 Operational oceanography: existing systems, developments and future potential

Convener: Flather, R.A.
Co-Convener: Bohle-Carbonell, M.

OPERATIONAL MODELLING OF THE EASTERN CANADIAN SHELF SEAS

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The continental shelf off the east coast of Canada is broad and irregular with a number of banks, channels and bays that strongly affect the shelf circulation. The subtidal circulation on the shelf is complex in comparison to some other shelf regions. In recent years, we have witnessed an increased need for operational modelling in the region. Applications include ice predictions, search and rescue, environmental control and fisheries management. As a part of the ongoing effort to develop an operational model for the Eastern Canadian Shelf. a number of different models have been developed. Currently, an operational model for the Scotian Shelf runs in real time and is available through our world wide web page at http://www-erp.phys.ocean.dal.ca . The model is based on a 3-D data assimilative model runs and uses forecast winds and statistical forecasts of the open boundary condition. A large scale model of the complete Canadian Atlantic Shelf suggests that we can use forecast winds and a larger domain to obtain open boundary conditions for the Scotian Shelf limited area model. The current operational model uses diagnosed density currents. We will discuss the implementation of a 3-D baroclinic model for the Gulf of Saint Lawrence - Scotian Shelf area.

A HIGH RESOLUTION INTEGRATED FORECAST SYSTEM OVER THE MEDITERRANEAN BASIN

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A high resolution operational system has been designed in order to forecast the state of the Mediterranean Sea and surges in the Northern Adriatic Sea. The system consists of a Limited Area Model (BOLAM), the wave model WAM and the ocenografic model POM (2D version) operating in cascade. The latter only runs over the Adriatic Sea, where the shallowness condition is fulfilled. so as to compute the elevation of the free surface at the three entrances of the Lagoon of Venice. Finally, a finite element model of the Lagoon will be used to predict the water level. LAM nesting procedures have been adopted to go from 30 km to 10 km resolution; the highest resolution fields force the WAM and POM integration. In the operational configuration. the meteorological fields are computed over a region of about $8 \cdot 10^6 km^2$ enclosing the Mediterranean Basin with 40 sigma levels in the vertical. Due to consequent computational costs. the LAM was implemented on a SIMD massively parallel computer (QUADRICS). performing at 2.12 GFlops sustained, so that a 24 hour forecast would take less than 40 minutes at the highest resolution. The whole integrated system, comprehensive of nesting procedures, will operationally run in about 2 hours for a 24 hour forecast. We show preliminary operative performances of the LAM-WAM-POM cascade, in one test case.

OPERATIONAL PROCESSING OF ALTIMETER DATA FOR CLIMATE STUDIES (DUACS PROJECT)

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The goal of DUACS EC project (Developing Use of Altimetry for Climate Studies) is to provide the scientific community with Near Real Time (NRT) fully processed altimeter data for assimilation in coupled ocean/atmosphere models. Three altimeter data sets, TOPEX and POSEIDON (T/P) IGDRs, and ERS2 FDPs, are preprocessed and then combined to form a snapshot of the sea surface height at a given time. The results of this analysis are compared to the precise delayed time data (GDR) to assess their quality. The treatment of the altimetric data within a defined time window is as follows. First a crossover analysis on T/P tracks is performed followed by the same analysis using ERS-2 tracks combined with T/P in order to minimize the orbit error. Second a long wavelength analysis is conducted to remove the along track correlated error with a minimal alteration of the large scale oceanic signal. Finally a multi-satellite optimal interpolation is carried out in order to obtain maps of the sea surface height at the desired time. We show that the sea level anomaly can be provided with a very good accuracy with respect to delayed time data. NRT DUACS altimeter data can thus be used to monitor large scale climatic signals such as El Nino events. The system will be operational starting in February 1998. It will also serve as a prototype for the future NRT altimeter data processing for the MERCATOR project.

DEVELOPPING OPERATIONAL SYSTEMS FOR OCEAN MONITORING : EXPERIENCE AND KEY POINTS OF THE SOPRANE SYSTEM ON THE EASTERN NORTH ATLANTIC

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Operational oceanography brings new requirements in the field of oceanography, and specific developments have to be done to build integrated systems bearing routine and near real time procedures. Along the past 6 years. SHOM/CMO has been following a pragmatic approach in developping ocean forecasting systems : from demonstration mock-up to pre-operational system. successive versions were routinely operated and regularly enriched by end-users requirements. SOPRANE is the latest release and is the first operational one: it aims at nowcasting and forecasting mesoscale ocean dynamics in the Eastern North Atlantic : near real time Topex/Poseidon and ERS-2 data are routinely assimilated : a QG model to provide weekly ocean bulletins. We put a special effort on three main points related to "operational" ability : (i) the near real time input data flow, (ii) the system outputs analysis and dissemination. and (iii) the overall system routine operation procedures. We will show the impact of these specific constraints on the oceanic system development and our solutions to answer them. As an intent to illustrate the cost of operational constraints applied to oceanography, main steps and key points of this long term experience - leading today to the Mercator project - will be also shown.

THE TAMPA BAY PHYSICAL OCEANOGRAPHIC REAL-TIME SYSTEM (PORTS)

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Real-time oceanographic and meteorological data from Tampa Bay, Florida, are collected by the Physical Oceanographic Real-Time System (PORTS), including current, water level, water and air temperature, wave height, period, and direction, barometric pressure, atmospheric visibility, and wind velocity. The data are collected every six minutes from sensor arrays at ten locations in Tampa Bay and are telemetered via line-of-sight radio to a central processor, which generates a real-time report available to the public by modem, Internet, or touch-tone telephone. Data from PORTS are used to drive an operational nowcast/forecast model based on the Blumberg-Mellor code. The nowcast/forecast model output is used to drive a contaminant trajectory model that can be used to mitigate damage from accidental spills of oil or other hazardous materials. All data are archived and are available via anonymous ftp to kelvin.marine.usf.edu or via World Wide Web from URL http://ompl.marine.usf.edu. A similar system is being developed for the entire west Florida coastal ocean.

ADAPTIVE MESH REFINEMENT AND ZOOM METHODS FOR OCEAN PREDICTION

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The ability to provide accurate local prediction of the ocean circulation, particularly in coastal areas, is an important goal of operational oceanography. This is generally achieved by embedding a high resolution local model in a coarse resolution regional model, which provides initial and boundary conditions.
In this paper we present a new approach to this problem, by making use of an adaptive mesh refinement method (AMR). The basic idea of AMR is to attain a given accuracy for a minimum amount of work. Therefore, estimates of the truncation error are computed, and refined grids are created (or existing ones are removed) where and when necessary. The amount of computation devoted to the fixed local fine grid in traditional nested grid methods is thus used now to ensure an accurate solution in the most sensitive regions of the flow (mostly fronts and eddies).
Numerical simulations in academic cases demonstrate that AMR leads to better local predictions than classical techniques, wherever the zoom region is located in the nested-grid approach. Moreover, it seems that AMR could be used for some long-term integrations of general circulation models, since the main statistical features of the solution obtained with an uniformly high resolution are conserved within a 10 to 20% range, while CPU cost is typically divided by 3. First results from the implementation of this method in a 1/3° PE model of the North Atlantic will also be presented.

DETERMINATION OF THE BEST DATA SET FOR THE SURFACE TURBULENT FLUXES COMPUTING : APPLICATION TO THE MERCATOR PROJECT

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In the frame of the MERCATOR project, a study has been engaged to determine the best choice of parameterization and origin of data used to force an oceanic model. To answer this question, an in situ data set will afford the opportunity to give some interesting perspectives. Ocean and coupled ocean-atmosphere models are particularly sensitive to the turbulent surface forcing. Indeed. a bias of only $10W/m^2$ of this forcing induces a strong drift of the climatic simulations performed with oceanic and atmospheric GCMs. In order to minimize this bias and therefore the climatic drift, numerous oceanic models applies corrections on the surface heat fluxes. To precise more accurately these corrections, we want to determine which atmospheric parameters must be used for computing the best surface fluxes. The mesoscale SEMAPHORE experiment data set is used because of the two months time series of different data sets, surface fluxes and new bulk parameterizations adapted to these data sets. Bulk fluxes algorithms used in atmospheric models will be tested with several atmospheric inputs coming from the ARPEGE model operational at Météo-France and from the model of the ECMWF. The sensitivity of the algorithms is tested when these algorithms will be carried out on and off line an atmospheric model, in order to evaluate the possibility of assimilating surface turbulent fluxes in an atmospheric or oceanic or coupled model.

MERCATOR, A FRENCH PROGRAMME FOR OPERATIONAL OCEANOGRAPHY

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The goal of the MERCATOR project is the implementation, within five to seven years, of a system which simulates the global ocean with a high resolution model, which assimilates satellite and in situ data, and which is operated in pre-operational mode. The system will later become fully operational, and is contributing to the development of a seasonal forecasting model. In addition the system will be useful for military and commercial applications.
The MERCATOR system consists of three main components :
- a primitive-equation ocean general-circulation model (the OPA model),
- a data assimilation algorithm, with a generalised coupler, PALM, solving its algebraic part;
- a data stream: observations, forcing fields, initialisation fields, validation data ..., from both space-based and in-situ sensors.

MERCATOR is endorsed by the seven French institutes interested in operational oceanography. It is developed in collaboration with ECMWF, and UKMO. MERCATOR is the French contribution to GODAE, planned for the years 2003-2005.
One shall emphasize the new developments which occured recently in MERCATOR: high-resolution (1/12th of a degree) modelling of the Atlantic ocean, construction of the generalized coupler PALM, ...

PERFORMANCE OF THE HIROMB

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The High Resolution Operational Model of the Baltic (HIROMB) has been run continuously since October 1995. It consists of a leveled primitive equation model, including level-2 boundary layer dynamics and a viscous-plastic ice model. Its main objective is to give daily forecasts of the water- and ice conditions of the Baltic Sea. In the validation we have compared the simulation with observations from regional studies as the DIAMIX or the Gulf of Riga Project as well as with the records of the cooperative monitoring network. In the talk emphasis is given to the ability of the model to extrapolate beyond the observations.

OA23

STATUS OF UK OPERATIONAL STORM SURGE FORECASTING FOR THE NW EUROPEAN SHELF

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Model-based tide-surge forecasting has been carried out operationally in the UK since 1978. The original system was based on a 35 km resolution 2-D tide-surge model using wind forecasts from a 110 km atmospheric model. Many enhancements to the forecasting system have been introduced over the years, mostly coinciding with improved computing facilities at the UKMO. Recent developments include: 1) introduction of high resolution models for sensitive coastal areas, for example, the Thames Barrier, the Bristol Channel; 2) pre-operational running of coupled wave-tide-surge models, where the tide-surge model incorporates wave-dependent surface and bed stresses utilising wave forecasts from the UKMO wave model; 3) pre-operational running of a 3-D model providing tidal and wind-induced currents; 4) development of a 3-D model involving prognostic temperature and salinity forecasts. Aspects of recent developments will be described, and some assessment of the improvements they bring to the forecasting system will be given.

HIROMB - AN OPERATIONAL 3D MODEL FOR THE NORTH SEA - BALTIC SEA

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HIROMB (HIgh-Resolution Operational model for the Baltic Sea) has been running operationally at SMHI (Swedish Meteorological and Hydrological Institute) since autumn 1995. The model has a nested configuration covering the North Sea with a 12 nm grid and the Baltic Sea with a 3 nm grid. The vertical discretization is made up of 24 levels with a layer thickness ranging from 4 m to 100 m. The forcing at the sea surface is provided by the daily atmospheric model and at the open boundaries by river runoff, tides and North Atlantic surge. In winter 1998, the model will be moved to a distributed memory computer (T3E) and the resolution will be increased to 1 nm in the horizontal and 50 levels in the vertical.

HOW AN OPERATIONAL OCEAN FORECAST SYSTEM HELPS DURING AN OCEAN SCIENTIFIC CRUISE. APPLICATION TO SOPRANE/CAMBIOS98 EXPERIMENT

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The SOPRANE system is an operational ocean forecasting system in the North-east Atlantic developped by the french Navy. It is based on a quasigeostrophic model of the Northeast Atlantic (Blayo et al. 1994), $1/10^{\circ}$ horizontal resolution. 10 levels assimilating real-time altimeter data from TOPEX POSEIDON and ERS2 with an optimal interpolation scheme using an empirical mode vertical extension scheme (De Mey, 1994). This system is aimed at providing real-time ocean mesoscale forecast to 1- navy users and 2- associated scientific ocean cruises. This system was used in pre-operational mode during ARCANE (Le Cann 1997) cruise in april 1997 and the CAMBIOS97 (Gaillard 1997), the forecast being sent to the ships in real-time. The SOPRANE system is operational since april 1998. The CAMBIOS98 cruise is ongoing (april may 1998) and the operational forecast are sent to the research vessel while the in-situ profiles collected at sea are used to update the forecast in near real-time. We show the results of this ongoing experiment. The oceanic circulation is described, and comparison between the forecast and the real-time XBTs and CTDs are shown.

COASTAL OCEAN PREDICTION AT THE NAVAL RESEARCH LABORATORY

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The Ocean Dynamics and Prediction Branch of the Naval Research Laboratory (NRL) conducts a coordinated program of Research and Development (R&D) in support of Navy operational ocean nowcast and prediction. This R&D effort covers domains from global and basin scales down to local beach scales. It includes sophisticated primitive equation ocean circulation models on global, basin and regional domains run on high performance computing platforms at the Fleet Numerical Meteorology and Oceanography Center (FNMOC) and at the Naval Oceanographic Office (NAVO). It also includes less sophisticated, but operationally significant, models designed to run on work stations and personal computers at the Navy's regional Meteorology and Oceanography Centers and on- scene. These latter capabilities can run stand-alone but also are designed to accept initial and boundary conditions available from the central site products.

NIVMAR: A STORM SURGE FORECAST SYSTEM FOR THE IBERIAN PENINSULA. IMPLEMENTATION AND HINDCAST BENCHMARK.

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A new storm surge forecast system, named Nivmar, has been developed for the Iberian peninsula. The system, which is run twice a day, is based on the employ of a 2-D barotropic version of the HAMSOM ocean circulation model. Model forcings are winds at 10 m and mean sea level pressures obtained from the Limited area model HIRLAM, which is operationally employed at INM (Instituto Nacional de Meteorologia). The resolution of the ocean model is 10' in latitude and 15' in longitude. Forecast horizon is 48 hours.
The system is also based on the employ of the measurements from the REDMAR tide gauge network, which is managed at Puertos del Estado. Results from harmonic analysis are employed to provide a prediction which includes information from all the tidal constituents. In order to improve the quality of the forecasted residuals, measurements from REDMAR are used with a simple data assimilation scheme during the post-processing of the ocean model results. The performance of the system has been tested during a 5 month stormy period (from November 1995 to March 1996) in the Spanish Coast. A large amount of data from this period was collected during the PROMISE (PRe Operational Modelling in the Seas of Europe) project covering both ocean and atmospheric information, being therefore an appropiated data set for validation and calibration of Nivmar. Results from the benchmark, which was done with analyzed winds in order to minimize the errors of the atmospheric model, show good results, specially on the Spanish Atlantic waters.

WAVE PREDICTION IN SHALLOW WATER.

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The Eurpoean MAST project, PROMISE, aims to develop models on which future operational modelling will be based. The project focusses on the physical processes which are important in coastal areas and thus a significant part of the project involves the study of surface waves. A shallow water version of WAM, a third generation wave model, has been developed and is being implemented on various scales in the North Sea. The shallow water version of the model has significantly improved efficiency in coastal areas, making operational use more feasible. The results from North Sea and regional models with grid scales down to 2.4km resolution are compared with wave data obtained from buoys, radar and satellites during the winters of 94/95 and 95/96. Using these results it is possible to assess the accuracy and suitablility of models like WAM for operational use in shallow water areas.

APPLICATIONS OF HF-RADAR IN OPERATIONAL OCEANOGRAPHY

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A High-Frequency (HF)-radar can be used to measure su   ce current fields and the spatial distribution of ocean wave directional spe ra. The physical mechanism behind is backscattering from a moving rough surface. These radars are deployed along the coast and cover an area of up to 50 km $\star$ 50 km, which can be observed continuously at 10 minute intervals.

Within the EU MAST-2 project SCAWVEX (Surface Current And Wave Variability EXperiment), work on HF-radar related techniques, algorithms and models, has been performed. The University of Hamburg developed a new HF radar WERA (WEllen RAdar). The wave algorithm has been developed by the University of Sheffield, the current algorithm has been adopted by the University of Hamburg from their previous CODAR (COastal raDAR) system. The spatial resolution of WERA can be selected between 1.2 km and 300 m.

HF radar will be an important tool for coastal management and harbour authorities. Integrated systems using radar measurements and 3-d models are to be developed for this purpose and can play an important role within EuroGOOS. Wave and current data from the SCAWVEX experiments will be presented to demonstrate the value of radar systems of this kind.

THE QUALITY OF OPERATIONAL WATER LEVEL FORECASTS IN DEPENDENCE UPON THE FORMULATION OF THE SURFACE DRAG

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The prediction skill of a numerical water level model for the North sea depends highly on the formulation of the meteorological forcing. Most of the water level variation (besides the tides) is caused by the wind stress followed by air pressure. Therefore an adequate formulation of the surface drag is needed. "Adequate" for operational use does not only mean physical and numerical accurate but also efficient in computation.
Ten different formulations of the drag coefficient were tested for their usefulness in predicting the water level in the North Sea especially the German Bight. A modelrun over a period of one year (the year 1994) was evaluated statistically for the water level residuum at high and low water.
The results show only small differences due to the drag formulation but indicate a slight improvement if the influence of ocean waves in terms of wave age is introduced.

SUBMARINE MONITORING OF GROUNDWATER DISCHARGE TO THE COASTAL ZONE

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Submarine springs and seeps are an overlooked source of fresh water and dissolved species to the ocean. Groundwater discharge into the ocean could occur anywhere that an aquifer with a positive head is hydraulically linked to the sea, i.e., most coastal areas. Volumetric estimates of their global extent range over several orders of magnitude. Submarine groundwater discharge has been documented to be significant for nutrient input in some regions, and could be of importance for issues relating to pathways of pollutants to the ocean as well as various naval operations (acoustic interference, etc.). Prior studies indicate that groundwater seepage is usually patchy, diffuse, and temporally variable. Methods are needed to find and measure direct groundwater flow into the coastal zone. We have shown that radon (Rn-222) can be a valuable tracer of direct groundwater discharge. Finding points of discharge is an important first step, especially when contaminated groundwater may be involved. Therefore, we have developed a detection system which could be deployed and provide monitoring either in real time, for a rapid site assessment, or moored for a more extended period to provide a continuous record. We have designed several models of an underwater radon detection system, suitable for deployment in a coastal zone. Various deployment scenarios are presented in the paper. Data may be transmitted over the hydroacoustic channel and written on the permanent data carrier. A modeling approach is used to quantitatively estimate the volumes of groundwater being discharged.

THE MAAMMED PROJECT: METEO-MARINE PREDICTION IN THE MEDITERRANEAN SEA

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The MAAMMed (Modelli Accoppiati Atmosfera Mare nel Mediterraneo, Coupled Atmosphere and Marine Models in the Mediterranean Sea) is a project supported by the Italian National Research Council (CNR) for the development of a pre-operative meteo-marine short-medium range prediction system in the Mediterranean Sea. The predicted quantities includes both atmospheric variables (sea level pressure, winds, precipitation, air temperature, etc.) and oceanographic variables (sea level, sea temperature, currents, surface wave spectra, etc.) computed accounting for the feedbacks of the sea on the atmosphere that are due to the variable temperature and wind wave dependent roughness of the sea surface. This presentation analyzes a 20-days long period (11-30 Nov. 1996) charactherized by a series of intense storms in the Adriatic Sea, high waves conditions and surge in its Northern part with the floodings of Venice. The results of the model are compared with observations and the implications of the study for meteo-marine prediction are discussed.

INTERANNUAL SEA LEVEL VARIATIONS AND THE Sa TIDE IN THE NORTHWESTERN SEISMIC ZONE

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Interannual sea level variations and the Sa tide are studied in order to find what contaminations can be expected in the seismic active zone in the northwestern Pacific. For the author's convenience, a specific reference is taken in a southern part of the Japanese Islands. The annual mean sea levels at the several tide stations studied for what were seen at the the 1995 Hyogo South Earthquake. The trends of the interannual variations of the sea levels at the stations suggests an effect of the tectonic activity. As for the Sa tide and its side robe at each station, especially, at Shirahama and Susami, a spectral analysis shows that one of the contaminant factors for the Sa tide is the Kuroshio as the western boundary intensified current. This current affects strongly to the sea level on the coast in the northwestern Pacific. When the current variations can be dynamically predicted well, then, the annual mean sea level can be taken as a reference for finding the tectonic and seismic variations.

AN OPERATIONAL MODEL SYSTEM FOR A TIDAL ESTUARY: ROUTINE INVESTIGATIONS AND SCIENTIFIC PROSPECTS IN THE EXISTING RIVER ELBE DEVELOPMENT

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For several years a predictive hydrodynamic model system for the Elbe estuary has been in operation building on the experience as a EUROMAR project. Currently the system is being adjusted to the specific needs of environmental monitoring and forecast. A further task is concerned mainly with analysis of operational forecast data for vessel traffic information. Some specialized work regarding coastal zone management has begun in connection with the MAST-III project OPCOM, i.e. work on the enhanced predictability of model boundary conditions taken from a North Sea model. First investigations with statistical methods exhibited strong correlations of waterlevels from both models with themselves (auto-correlations) and also significant correlations with the forcing data (wind speed, atmospheric pressure). Naturally, the auto- and cross-spectra of the processes did show strong peaks on the frequency of the M_2 tide, on the spring-neap cycle and its harmonics. However, reducing a measure of the first-order prediction error by subtracting the deterministic trend and the periodic components led to a variance reduction of up to 90 %. Based on these results the error of waterlevel predictions at the open boundary could be reduced significantly. Further work concerning other hydrodynamic variables and other statistical approaches are currently being done within the OPCOM project.

WAVE FIELD EVOLUTION IN COASTAL REGIONS

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Wave measurements were made with a pressure sensor and an electromagnetic currentmeter in shallow waters where average depth was about 14 m. Radar images were also acquired from the study region, the shelf area between Islas Coronado and northwestern Baja California coast. The main goal of our project is to study the wave field evolution while propagating towards the coast on intermediate to shallow waters. In particular, look at the wave spectra spatial variability and determining its impact on coastal engineering applications and maritime operations in the area. How important is the spatial variability and how well it is reproduced by state-of-the-art predictive models, are the key questions to be answered by our research project. Numerical simulation of wave spectra is carried out using the SWAN model. Intercomparisons of wave spectra from a) insitu measurements, b) radar images, and c) numerical simulations show the complexity of the phenomenon in this shallow water environment. The possible impact of long term monitoring by imaging radars and insitu instrumentation is addressed. It is of particular importance the possibility of monitoring the wave field and providing real or near-real time information over the spatial domain, since oil tankers unload in this region through bouys and underwater pipes.

OCEANOGRAPHIC NOWCAST/FORECAST MODEL SYSTEMS FOR BAYS AND HARBORS

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Nowcast/forecast model systems for bays and harbors are being developed and tested by the National Ocean Service (NOS) in support of safe and efficient navigation. The greater accuracies in water level (for determining under keel clearance) and currents (for safe maneuvering) needed to help prevent groundings and collisions of today's huge tankers and cargo ships have already led NOS and other institutions around the world to implement real-time oceanographic systems. This is a first step beyond astronomical Tide and Tidal Current Tables, which cannot include the important effects of winds and river discharge. Such real-time data, however, is useful only at the time it is taken (or a couple of hours into the future if conditions change slowly). The mariner, however, needs accurate information on water levels and currents 24 hours or more into the future. (If a maritime accident should lead to a hazardous spill, nowcast/forecast currents also improve oil spill clean-up operations by better predicting the movement of the spill.) A skillful nowcast/forecast model system for a bay requires (in addition to a calibrated, verified model of appropriate dimension and resolution, with accurate bathymetry) most or all of the following: (1) QC'd real-time oceanographic and meteorological data and data fields; (2) open-boundary forecast water levels from a coastal/shelf forecast model; (3) forecast winds and other meteorological parameters from weather forecast models (one over the coastal/shelf model and a higher resolution version over the bay); (4) forecast discharges from a river model; (5) a data assimilation system for the nowcasts; (6) an ensemble averaging system for the forecasts; and (7) an information system for disseminating predictions and error estimates to the users. The program at NOS presently involves regional high-resolution hydrodynamic numerical models of Chesapeake Bay, Galveston Bay, and the Port of New York and New Jersey, with forecast boundary conditions provided by either an East Coast ocean model, a Gulf of Mexico oceanographic model, or an individual shelf model, each driven by forecasts from the NWS's ETA weather model. Nowcasts and 24-hour forecasts of water level and currents are presently produced twice daily and presented in graphical form on a WWW Home Page for evaluation purposes.

WaMoS II: An Operational Wave Monitoring System

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Many offshore and coastal operations are critically dependent on the prevailing meteorological and oceanographic conditions. To enhance the security of people and buildings, a reliable monitoring system is necessary which can utilize routine sea state measurements, even during strong weather conditions.
The new operational wave monitoring system, WaMoS II, is presented. This system is based on a commercially available nautical X-Band radar, normally used for ship traffic control. The measurement is based on the backscatter of microwaves from the ocean surface that can be visible as sea clutter on the screen of a nautical radar. The system requires a minimum wind speed of about 3m/s but it operates extremely reliable in rough weather conditions. The system delivers information about the two-dimensional wave spectra and the mean surface current velocity. Therefrom all the important sea state parameters as significant wave height, directions and wave periods are derived in real time (2 minutes).
A brief outline of the required system components and the data analysis method is given. Furthermore an overview of successfully deployed operational WaMoS stations is presented. A comparison between WaMoS II derived data and in-situ buoy data is presented. Both data sets show an excellent agreement of more than 90%.

SEA LEVEL FORECAST IN THE GULF OF GDAŃSK ON THE BASIS OF INTEGRATED SYSTEM OF MARITIME OPERATIONAL HYDROLOGICAL FORECASTING

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The aim of the presented paper is a trial to uniformize the terminology used in hydrological forecasting and to present the actual potential of the Maritime Branch of Institute of Meteorology and Water Management (OM IMGW) in Gdynia in forecasting of short term sea level changes in the Gulf of Gdańsk. Selected terms commonly used in the metodies of modern hydrological and meteorological forecasting are explained. Main statistical features of the sea-level variability at the Polish coasts of Gulf of Gdańsk are discussed. Methods applied to hydrological forecasting in Hydrological Section of Maritime Weather Office in Gdynia are shortly described and the organization of forecasting process by means of an automated Integrated System of Maritime Operational Hydrological Forecasting (ISMOH) is presented (the system was prepared in frame of EC project ERB CE PDCP). Planned development (assimilation of new meteorological forecast model results, new area etc.) is explained.

COMPARISION BETWEEN OBSERVED, HINDCAST AND NOWCAST SEA LEVEL ON THE SOUTHERN BALTIC SEA

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The aim of the presented paper is a verification of the mathematical models used in hydrological forecasting in Poland (sea-level forecast along the Polish Coast). The models are working under the Integrated System of Maritime Operational Hydrological Forecasting (ISMOH) for the last year. The forecast is issue every morning at 6.00 UTC with the lead time up to 24 hours. The results of comparison between observed and calculated sea level are shown for 3 intervals of sea level (low levels, mean levels and high levels) and for 4 section of wind direction (N, S, E, W).
The influence of the error of the meteorological forecast on the hydrological forecast was investigated by compression the hindcasting and nowcasting of sea level.

A NEW AIRBORNE GRAVIMETRY/ALTIMETRY SYSTEM FOR COASTAL OCEANOGRAPHY - THE AGMASCO PROJECT

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Within the EU MAST-III project AGMASCO, an Airborne Geoid Mapping System for Coastal Oceanography has been established to determine geoid and sea surface topography in coastal and shelf areas. It is based on most advanced sensor technology (accelerometer, laser/radar altimeter, GPS, INS) for gravity and sea surface height data acquisition. The hardware can be operated over sea as well as over land, therefore bridging important data gaps. In combination with satellite data, more detailed geoid and sea surface models may be developed in coastal and polar regions. First demonstration projects (Skagerrak/1996, Fram Strait/1997) and a full application project (Azores/1997) has been performed. The already achieved results seem to reveal a 10 cm accuracy regarding geoid and sea surface heights. The airborne measurements along the ERS-2 and Topex/Poseidon tracks allow a direct comparison of the different techniques and will show the advantages of each system.

THE POTENTIAL OF NEURAL NETWORKS FOR OPERATIONAL OCEANOGRAPHY

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Neural Networks (NN) are generic black box models that must be calibrated from observed input-output combinations. Major advantages of NN are their capability to 'learn' nonlinear input-output relations, and the low computational effort that is needed to prepare and apply these models. Therefore NN are especially suitable for applications under operational conditions.
As potential oceanographic applications of NN operational predictions of waterlevels/currents/waves can be mentioned, as well as control of structures (e.g. storm surge barriers) and/or prediction of forces on structures, or even applications for data validation/interpretation (e.g. remote sensing data). As practical examples NN-applications performed by the North Sea Directorate can be mentioned. In these applications currents at the entrance channels to the ports of Rotterdam and Amsterdam were predicted from hydro-meteorological time series (observed and/or astronomically predicted waterlevels, river Rhine discharges, and wind velocities). These NN are presently applied in operational mode for guidance of deep draughted ships to the ports. Apart from this another NN is developed for operational water level predictions at Hook of Holland.
In standard form NN are a fully data-oriented approach, and its domain of applicability and accuracy are limited by the quantity and quality of the available data set. If also system knowledge is included in a NN, its performance can significantly be improved, however. At Delft Hydraulics such 'hybrid' models are presently developed and applied. Their (additional) potential for oceanographic applications will be addressed in the presentation.

JASON-1 ALTIMETRY AND OPERATIONAL APPLICATIONS

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The scope of the presentation is double: 1. anticipate the objectives of potential operational applications of altimetry with associated accuracy and reliability requirements in terms of data quality and availability, 2. display the required performances of the Jason-1 altimetric system with respect to the operational and science objectives.
Following TOPEX/POSEIDON that was intended to help scientists to better understand the ocean circulation and its impact on the climate of the Earth, Jason-1 is devoted to lengthen the series of high accuracy measurements that began with TOPEX/POSEIDON in order to monitor the inter-annual evolution and separate transient phenomena from secular variations. To reach this goal, the Jason project is designing, developing, integrating and testing a satellite system with its suite of instruments to be launched early 2000, together with a multi-mission ground system. To take into account operational users, a new capacity consisting in distributing near real time measurements will be set up. Jason-1 requirements in terms of mission success and data availability will be reviewed, and a pre-launch error budget will be presented.

STRUCTURED DATA MODEL INTEGRATION TO ASSESS THE STATE OF SPM ON THE NORTHWEST EUROPEAN SHELF

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Suspended particulate matter (SPM) is an important parameter for determination of the light availability for primary production as well as for transport of adsorbed pollutants. Information on the actual SPM distribution and a better understanding of the SPM processes is therefore important for management of the North Sea and its ecosystem. The paper addresses the unique potential of structured integration of synoptic NOAA/AVHRR images and dedicated transport modelling for the above. Mass conserving transport models can provide the scaling of individual synoptic RS images that are needed to ensure consistency of interpretation of successive images. On the other hand, the spatial SPM characteristics contained in RS images are ideally suited to validate SPM transport models in combination with the rather sparse in-situ data. In the paper a Goodness-of-Fit criterion is presented which allows for simultaneous integration of in-situ and RS data with a model. This approach was proven successful for the Dutch coastal zone in earlier studies which showed that optimal use of available data and model information can so be attained. The methodology has now been improved and applied on a North Sea wide scale. Results will be shown for the year 1990 and 1994, followed by a discussion on various practicalities. The study is part of the MAST-3 funded PROMISE project.

DYNAMIC REGRESSION AND EOF FORECAST MODEL APPLIED FOR SPLITTING LINEAR AND NONLINEAR FORCING OF THE BALTIC STORM SURGE

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A model of linear, dynamic relationships of autoregression and regression is used in forecasting daily sea levels and storm surges on the Polish Baltic coast with a 24h lead time. The predictors are the EOF of the atmospheric pressure and sea level fields. The model was developed from a two-year set of measurements with a 3h sampling step and validated on a 7-month data set. The daily sea level forecast for 5 ports is characterized by an rms error which occurs in the 7-9 cm interval with a probability 79%. This error in the corresponding 14-18 cm interval has probability 96%. Storm surges are forecast probabilistically on the basis of the upper confidence limit. For 7 powerful storms recorded in 5 ports, the mean absolute forecast error lay within the 14-18 cm interval. Computations have been performed to separate linear from non-linear effects in the generation of very high and violent storm surge recorded at 5 tide gauges. These show that linear storm surge forcing is considerable.

OA24 Marine data management: assimilation, hindcasting and nowcasting

Convener: Evensen, G.
Co-Convener: Gerritsen, H.

TEMPERATURE ASSIMILATION IN THE NORTH SEA

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A simple interpolation method based upon a Kalman filtering approach is presented. This enables sea surface temperature observations (provided by the Pathfinder satellite-derived AVHRR data set) to be assimilated into a meteorologically forced three-dimensional baroclinic model of the North Sea. A comprehensive set of in-situ measurements collected during 1989 forms a base against which error statistics are calculated. A series of numerical experiments demonstrates that the method produces a large improvement in the model's predictive performance. The results compare well with theoretical calculations based upon the error statistics.

NONLINEAR INVERSION OF IN SITU DATA FROM OCEANIC DISSOLVED-PARTICULATE EXCHANGES

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Biogeochemical models describing the dissolved-particulate exchanges in the water column are 1+1 dimensional and based on a system of nonlinear Partial Differential Equations. We show that the direct solutions may adopt complex dynamical behaviours (e.g. chaotic), as the equations are nonlinear and coupled and that changes of the exchange rates may trigger system bifurcations. To constrain the model with a data set, we must be able to (i) accurately determine the state variables at a given time and to (ii) recover the exchange rates. The first issue aims at defining the time evolution of the chemical elements concentrations in the dissolved and particulate phases. The second one allows to characterize the long-time dynamical behaviour and predictability of the water column system. First, we partially solve them by using synthetic time series extracted from direct integrations of the model. The data assimilation and inversion are performed using a sequential nonlinear optimization algorithm. We then tackle with the assimilation-inversion of *in situ* data, using a two years time series of trapped, suspended and dissolved material data collected at two sites in the tropical Atlantic Ocean (EUMELI sites). Interesting conclusions but also new questions emerge from this confrontation between the model of the water column dynamics and the *in situ* data.

WAVE MODELS ANALYSIS IMPROVEMENT BY USING ALTIMETRIC WAVE HEIGHTS

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The aim of this study is the improvement of the wave fields produced by the sea-state models. In order to obtain the best wave height estimation, we merge the VAGATLA model outputs ($H_{1/3}$) and the TOPEX altimeter measurements (SWH) by using an optimum interpolation (O.I.) scheme. The O.I. consists in solving a linear system whose the matrix and the second member are statistical fields, theoretically computable from the data, but with difficulty accessible in practice. We have used the results of several cross-calibration to define the equations that allow to close the system. Then the statistical parameters required by the O.I. scheme have been computed from three years of TOPEX/VAGATLA colocalized data. The resulting wave fields exhibit a reduction of the distance between the buoy data and the model over 40% (15 cm) in bias and 5% (4 cm) in standard deviation. An adaptative method under development should allow us to improve these encouraging results by a best fit of the scheme coefficients.

AN EXPERIMENTAL SYSTEM FOR MERCATOR

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The goal of the experiment is to implement in 1999 a system which will simulate the north Atlantic and Mediterranean circulations at a resolution of a twelth of a degree and with TBD vertival levels. It is foreseen as an initial implementation of Mercator and will serve as a feasibility study for the integration of the main components of Mercator: the ocean circulation model, the data assimilation procedure and the data stream.
The ocean model is based on OPA a primitive equation model developped at LODYC (Paris). The atmospheric forcing are provided by the ECMWF reanalyses. The rigid lid hypothesis is made. A mixing layer based on a TKE closure is used. The ocean model is coupled with a semi-diagnostic model of the sea-ice cover.
The data assimilation method will rely on the code SOFA an Optimal Interpolation scheme developped at LEGOS (Toulouse). The system will be assimilating altimetry observations from T/P and ERS. SOFA uses empirical orthogonal functions of the vertical covariance matrix to transfer the information from the surface to all ocean layers. In a near future, SOFA will be developped to be able to assimilate in-situ data as well.
Real time is a key aspect for operational oceanography. It should be included in the experimental system and will be planned for the years 2000-2001.

REDUCED KALMAN FILTER APPLIED TO DATA ASSIMILATION WITH STRONGLY NON LINEAR MODELS

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The aim of this work is to analyze and improve the behaviour of a Singular Evolutive Extended Kalman filter (SEEK) in the context of data assimilation into strongly non linear ocean models. This filter, introduced recently in Pham et al. (1995), tries to make correction primarily along the fastest error growing error directions. It is easily shown that, for a linear model, the SEEK provides the subspace of the first eigenmodes of the tangent linear model. However, with a highly non-linear model, the filter may be unable to keep track of these modes and accordingly correction would be made inefficiently.
This phenomenum will be illustrated with the well known Lorenz chaotic model. We will see how the SEEK filter can sometimes fail to assimilate the true model trajectory, and how such problems can be avoided by making use of the equation describing the temporal evolution of the eigenmodes. Note that this leads to a computing procedure quite similar to the SEEK, without making any costly use of adjoint equations.
Application of these variants of the method in the realistic context of a north Atlantic high resolution circulation model will also be described

HINDCASTING THE SYNOPTIC VARIABILITY IN THE GULF OF SAINT LAWRENCE

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The Gulf of Saint Lawrence is one of the world's largest semi-enclosed ocean basins. Research in this area focused on the basic estuarine circulation of the Gulf of Saint Lawrence. Little is known about the variability at synoptic periods (2-10 days) and what causes it. We address the questions of relative importance of local wind versus remote forcing through the open boundaries of the Gulf. We hindcast the flow in the Gulf for a period of two winter months during 1986 and 1987. First, we assess the role of the local wind forcing. Then, we account for the effects of open boundaries using an adjoint based data assimilative shallow water model. The model results suggest that boundary forcing is critical for resolving the synoptic variability in the Gulf of Saint Lawrence. The amplitudes of the boundary forcing can be related to the large scale wind forcing over the Labrador and Newfoundland Shelves. We therefore explore a suboptimal scheme for forecasting the flow based on forecast winds and data assimilative runs.

SENSITIVITY TO OBSERVATIONS IN A COASTAL MODEL OF THE NORTHWESTERN MEDITERRANEAN SEA

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It is interesting to study the impact of observations in view of data assimilation in meso-scale/coastal circulation models. Indeed, it is important to know which kind of data and location are most useful in order to constrain models. In a data assimilation analysis scheme, it can be showed that the analysed state of the ocean is the the sum of the forecasted state and a linear combination of the representer fields. Each representer is the influence function of a data point on the field. The representers can be calculated from the forecast error covariance matrix which is estimated by a Monte Carlo method. This methodology is applied to the Princeton Ocean Model, a free surface, sigma coordinate, primitive equations coastal model set up for the coastal area south of France and Italy. The influence of observations (altimetry, current measurements, sst..) on the behaviour of the Liguro Provencal current is analysed.

ASSIMILATION OF ALTIMETRIC DATA IN EDDY-RESOLVING PRIMITIVE-EQUATION MODELS

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The Grenoble Group has developed a suite of assimilation schemes for ocean circulation models. The degree of sophistication of the methods is very wide, as the schemes include nudging, optimal interpolation, simplified Kalman filters and the variational-adjoint technique. A number of schemes have been developed at the research level only, while others have been implemented up to pre-operational levels. A new data assimilation scheme derived from the Kaman Filter has been elaborated recently in the perspective of the French MERCATOR project. The method relies on the concept of a reduced-order basis which evolves with time according to the system dynamics. The primary motivation for developing the so-called Singular Evolutive Extended Kalman (SEEK) filter was to control the mesoscale activity of mid-latitude oceanic flows using altimetry and thermal imagery, investigating how well surface observations of the ocean can be used to reconstruct the time evolution of eddy fields. The algorithm has been formulated in quite a general fashion to make it tractable with a large variety of ocean models and measurement types. Examples of the filter implementation will be shown, illustrating the response of the assimilation scheme to several ocean observing systems.

AN ENSEMBLE KALMAN FILTER WITH AN ISOPYCNIC COORDINATE OCEAN GENERAL CIRCULATION MODEL

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The Ensemble Kalman Filter (EnKF) has been proposed as a new sequential data assimilation method capable of handling strongly nonlinear models to an acceptable numerical cost. The method resolves the major deficiencies in the traditional Extended Kalman Filter when used with nonlinear dynamics, e.g. unstable error covariance evolution due to the use of a linear error covariance equation and extreme numerical cost. Here the EnKF method will be presented together with examples from a recent implementation with the Miami Isopycnic Coordinate Ocean Model. Focus will be on the prediction of error covariance statistics and the potential for such a system in operational use.

A MARINE INFORMATION SYSTEM (MIS) IN SUPPORT OF A COASTAL ZONE MONITORING AND PREDICTION SYSTEM

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An efficient and accurate coastal zone monitoring and prediction system requires the integration of observations and numerical models. The integrated use of observations and models is best done using data assimilation methods, which in an optimal way merges the information about the dynamics contained in the model with the information about the current state of a system contained in a set of measurements. The observing system will have to consist of oceanic in-situ data, remotely sensed information, and observations of biochemical variables. The MIS proposed here is designed to access, store and manipulate the different data in-order to prepare them for easy integration in data assimilation models. Important design considerations of such an information system include, among others (1) downloading of real-time data from distributed sites, (2) pre-processing of data, including format and resolution conversion, inter/extrapolation and data quality checks, (3) efficient storage and retrieval of remote sensing, in-situ and simulated data, (4) data exchange with the numerical models, and (5) dissemination of analyses and predictions to end users.

TUNING WEIGHTS AND SMOOTHING PARAMETERS OF THE GENERAL INVERSION

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The general inversion of a model involves the statistics of data and model errors. However, little is known about them, particularly about the latter. We propose an approach to estimating weights and smoothing parameters. The weights are responsible for a compromise between different sources of knowledge about a modelled phenomenon. Smoothing acts as a regularizer providing well-posedness of the data assimilation problem. Instead of using non-diagonal dynamical covariances we offer to smooth kernels of observational functionals. Since various parameters of the general inversion are of different nature, rules for choosing them would differ from each other; this circumstance has been ignored with other estimating techniques. Because the inverse solution depends on the ratio of the error variances, the dynamical error variance can be fixed; we propose that the other weights maximize the sum of corresponding cost terms. The smoothing parameter can be chosen as large as possible and such that its change does not affect the weights notably. The procedure has been tested for a weak constraint formulation of a 1-D model for tides in a channel (with application to the Tatarskiy strait). The study revealed that with the optimal weights and smoothing parameter, the standard deviation of the inverse solution from data not assimilated into the model was close to its minimum value.

IMPROVING THE MEAN STATE OF A MODEL BY ASSIMILATING MEAN TOPOGRAPHY TOGETHER WITH SSH ANOMALIES: RESULTS FROM THE DYNAMO PROJECT

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The assimilation of the 1992 - 1993 ERS-1 TOPEX/Poseidon SSH anomalies into the Level model fo the DYNAMO project leads to a better representation of the near surface variability. But the assimilation of a 1 year period of the time varying part of the altimeter signal does not change the mean model circulation significantly. Using a suboptimal, statistical assimilation scheme, the mean model state is partly determined by the SSH-climatology of the undisturbed model. Replacing the SSH statistics of the Level model by the equivalent of the DYNAMO isopycnic model introduces a mean circulation close to that of the latter model, without loss of the high surface variability. An independent estimation of the mean surface topography for the Northwestern Atlantic, inferred from hydrography and altimetry, is used as an SSH-climatology to attempt a model state as realistic as possible. In the vincity of the Gulf Stream extension and the North Atlantic Current the near surface currents and related heat loss is much improved. Comparison with a WOCE section shows that the subsurface watermass distribution is closer to the observation now.

A 40-YEAR COUPLED HINDCAST OF OCEAN AND ATMOSPHERE IN THE NORTH SEA REGION

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A regional 40-year hindcast (1957-97) of the atmosphere-ocean system of the North Sea and surrounding areas will be performed. using the NCEP reanalysis data as a global forcing field. To determine the model set-up for the long-term simulation sensitivity studies are performed.

It is a problem inherent in using a global model to provide the forcing, that regionally developing small scale structures are easily destroyed by the coarse information prescribed at the boundaries. Usually, to adress this problem a rather large area is used in the regional model to allow small scale features to develop in the region of interest. Here, a different approach is attempted: throughout the model domain, the large scale features (the largest Fourier components) from the global model are nudged into the regional model. making it possible in return to keep the lateral boundary rather small and thus giving the regional model more freedom on small scales in the interior.

Comparisons to observations and to simulations with a different model are presented.

T-S DATA ASSIMILATION IN A 3D CIRCULATION MODEL TO OPTIMIZE THE TURBULENT VISCOSTY

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The Berre lagoon (France) is a semi-enclosed basin with 6 m depth average and 15×15 km^2 of surface area. Salinity and temperature profiles are measured by an automatic station every half a hour. Due to river Durance discharge in the north and Mediterranean sea intrusion in the south, the hydrological situation is often strongly stratified. The vertical mixing occurs only with high wind. Modelling the basin circulation during such a process with a 3-D primitive equation model requires an accurate parametrization of the turbulent vertical viscosity (ν_t). A classical approach consists in using a turbulence model like the k-L or k-ϵ ones. Here, an alternative approach consists in considering ν_t. space and time dependent, as an input parameter controlling the system. ν_t is optimized, iteratively, for each vertical level and half a hour period, in order to minimise the discrepancies between the simulation results and the data. This iterative procedure requires to solve an adjoint model to assimilate the data. This optimal control method is applied on a 3-days wind event and gives simulation results very closed to station data. It can be expected that the simulation for the rest of the basin is better than a classical k-L model simulation without data assimilation.

WEAK-CONSTRAINT VARIATIONAL ASSIMILATION OF ALTIMETER DATA IN A NON-LINEAR OCEAN MODEL

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The object of this numerical study is to use a weak-constraint variational method of data assimilation with a primitive equation model. We consider the 4D-PSAS algorithm (Physical-Space statistical Analysis System) that includes model error. This algorithm minimizes an objective function J_Λ defined on the dual of the data space by solving the Euler-Lagrange equations iteratively. The gradient of J_Λ is obtained by a backward integration of the adjoint equations followed by a forward integration of the direct equations forced by the adjoint variable.

The algorithm is tested on MICOM (Miami Isopycnic-Coordonate Ocean Model) in an oceanic box, assuming a schematic stratification with 4 immiscible layers. Each layer is characterized by its density and its dynamics is governed by the Shallow-Water equations. The oceanographic context of our numerical example is a description of the Gulf-Stream circulation on a β-plane.

The experimental strategy is to perform twin-experiments with simulated data in order to assess the performance of our assimilation method for the case of altimeter data. The fundamental issue is to verify the feasibility of adapting the 4D-PSAS algorithm to a non-linear model.

APPLICATION OF THE KALMAN FILTER FOR DATA ASSIMILATION IN COASTAL AREA MODELLING

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Data assimilation procedures based on the Kalman filter (KF) have been implemented into a 2D hydrodynamic modelling system (MIKE 21) for assimilation of tide gauge measurements. The KF provides a successive correction of the state of the system as well as an estimate of the corresponding uncertainty by taking into account the inherent uncertainties, including errors in the open boundary conditions, errors in the meteorological forcing, and measurement errors. The paper presents a review of recent developments and applications of the KF in MIKE 21. Two different procedures have been analysed, respectively, an extended KF based on a reduced rank square root approximation of the error covariance matrix and an ensemble KF based on a Monte Carlo simulation approach for propagation of the errors. Results from an intercomparison study are presented that demonstrate the general performance of, and differences between, the two methods. In addition, two application examples are presented. First, the data assimilation scheme is applied for improvement of the prediction of extreme storm surges in the North Sea, applying the ECAWOM data set. Secondly, a long-term simulation of corrected water level and velocity fields as boundary conditions for a 3D numerical model of the North Sea - Baltic Sea region (DYNOCS project) is presented.

AN INVERSE FINITE ELEMENT MODEL OF THE LARGE SCALE CIRCULATION IN THE SOUTH ATLANTIC

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A finite element model in primitive variables and its adjoint were developed for the reconstruction of the large scale circulation in the World Ocean. Finite elements formulation of the model treats both the dynamical constraints and the data assimilation algorithm from a single viewpoint of variational formalism. The major advantage of the method is a possibility to work with unstructured grids, which can be refined in the regions of strong currents and thus save computer resources by reducing the number of degrees of freedom related to dynamically inactive regions of the ocean. The present preliminary study is focused on the application of the steady state version of the model for the recovering of the circulation in the region of South Atlantic between $76.5°S$ – $32.5°S$ and $66.5°W$ – $21.5°E$ on the base of available climatological data. The following data sets are utilized: Southern Ocean Hydrographic Atlas, Topex-Poseidon sea surface elevation data, annual mean wind stress data and preprocessed hydrographic sections data. The flow through the open boundaries of the region and wind stress uncertainties are chosen as control variables. The assimilation results show reasonable model–data consistency for specified data error covariance structure.

Optimal Interpolation and Statistical Analysis of SST fields from ATSR

Since August 1991 the Along Track Scanning Radiometers (ATSR-1 and ATSR-2) have provided a near-continuous global sea-surface temperature (SST) record with a precision of approximately 0.3K. This accuracy is associated with spatially-averaged SSTs which are generated at ten arcminute resolution. Daily coverage is around one third of the Earth's surface, with a week's observations typically required to achieve a fairly full global SST field (allowing for 50% cloud cover).

However climate models ideally require continuous fields at a high spatial and temporal resolution. Production of such fields from an irregularly and sparsely sampled data set presents formidable problems. Traditional interpolation techniques such as Fast Fourier Transform are not suited to the irregulary sampled data, and general matrix inversion techniques are prohibitively expensive for the array sizes involved (around 2000x1000 for a global field at ten arcminute resolution).

We describe the application of a multiresolution estimation frame work which offers computionally efficient methods for the interpolation, analysis and smoothing of extremely large data sets; the method also provides realistic error estimates. The recent enhancement of the technique to offer the possibility of assimilating data over time is described, and results from this dynamic estimation are presented.

A NOWCAST/FORECAST SYSTEM BASED ON THE GLOBAL NRL LAYERED OCEAN MODEL (NLOM)

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A 1/4 degree global version of the Naval Research Laboratory (NRL) Layered Ocean Model is currently being transitioned to Fleet Numerical Meteorology and Oceanography Center (FNMOC) to run as a nowcast/forecast system. Real-time altimeter sea surface heights (SSH) from Topex/Poseidon and ERS-2 obtained from the Altimeter Data Fusion Center (ADFC) at the Naval Oceanographic Office are assimilated into the model. Observations from the US Navy's Geosat Follow On (GFO) mission will be used as soon as the data become available. The data assimilation method is a nudging technique. Altimeter observations give only information about the sea surface height. A statistical inference technique is used to infer corrections to the lower layers of the model and a geostrophic correction is used to update the velocity outside the equatorial region. SSH time series from the model before and after assimilation are compared to an independent set of tide gauge sea level observations. This global model is used to provide boundary conditions for a high resolution model of the west coast of the Unites States. Future plans include upgrading the global model to 1/8 degree with embedded higher resolution basin-scale models of the Pacific and Atlantic Oceans.

STUDYING MARINE ECOSYSTEMS IN TERMS OF DATA ASSIMILATION

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A weak constraint variational formulation for a simplified four component ecosystem model is defined, and minimized using gradient methods. An ordinary gradient steepest descent scheme is compared to a more elaborate nonlinear conjugate gradient scheme denoted by the Fletcher and Reeves method. Several data assimilation experiments are performed in which the data are generated from an "exact" forward model integration. To make the experiments more realistic, normally distributed noise is added to the measurements. Properties like the sensitivity with respect to the data density, and also with respect to the assimilation interval, are investigated. Also, an experiment with measurements of only the phytoplankton ecosystem component is performed. Satellite ocean colour data represent the major part of currently available observations, and such data sets may be used to measure the phytoplankton compartment. Thus, showing that it is possible to obtain good results also for the other ecosystem components when only phytoplankton is measured seems to be of vital importance for creating a preoperational marine data assimilation system. The simple ecosystem model used is easily extended to more elaborate ones, like the well accepted and commonly used FDM-model (Fasham-Ducklow-McKelvie).

SENSITIVITY ANALYSIS OF AN INTEGRATED MODEL FOR SUSPENDED SEDIMENT TRANSPORT IN THE NORTH SEA

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As part of the MAST-3 project PROMISE, the sensitivity of the SPM transport model is studied for the propagation of (model and data) errors in meteorological, hydrodynamic and wave parameters as well as empirical coefficients in the formulation of the erosion and sedimentation processes and sediment inputs.

Accuracy and efficiency are two key words in modelling interacting physical processes in an optimal way: given some pre-defined objective of the integrated model, how to link the models and comprehensive data sets in an efficient way that meets the accuracy requirements. This includes, a.o., establishing the type and accuracy of the representation of the processes involved: how can they be adequately represented (that is with sufficient accuracy and resolution), by detailed model computations or, rather, by extracting information from comprehensive data sets.

The model performance is quantified using a pre-defined Goodness-of-Fit criterion. This criterion is an appropriate measure for the difference between the computed and observed (RS and in-situ) concentrations, given the modelling objective, where the representativeness of the concentration observations is explicitly taken into account. By means of adjoint modelling techniques the model's sensitivities for the residual flow field, bottom shear stress, sedimentation velocity and sediment dumpings are assessed. Based on the temporal and spatial variability of these sensitivities, a low-dimensional parameterization of the model error is defined that is well suited to calibrate the (transport) model.

A SINGULAR EVOLUTIVE EXTENDED KALMAN FILTER

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A modified form of the extended Kalman filter is proposed to assimilate oceanic data into numerical models. Its development consists essentially in approximating the error covariance matrix by a singular low rank matrix, which amounts in practice to making no correction in those directions for which the error is attenuated by the system. This not only reduces the implementation cost to an acceptable level but may also improve the filter stability as well. The "directions of correction" of the filter evolve with time according to the model evolution, which is the most original feature of this filter, distinguishing it from other sequential assimilation methods based on the projection onto a fixed basis of functions. A method for initializing the filter based on the emrirical orthogonal functions is also described. Examples of the filter implementation will be shown in the tropical Pacific ocean and in the North Atlantic.

ESTIMATION OF ANALYSIS ERROR STATISTICS FOR VARIATIONAL DATA ASSIMILATION

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Tri-dimensional variational data assimilation (3D-Var) is used operationally in a number of meteorological centers (Statistical Space Interpolation system at NCEP, 3D-Var at Météo-France) and four-dimensional variational data assimilation (4D-Var) became operational at ECMWF recently. OI schemes provide an estimation of standard deviations of analysis error. This information on the quality of the analysis is lacking in variational assimilations and must be estimated in some way using additional procedures.
In addition, the estimation of analysis error covariances at the end of the assimilation period for 4D-Var and of the forecast period for 3D-Var, is necessary for cycling variational assimilations.
The author proposes a method for estimating the analysis error covariances. It uses standard deviations in physical space and an operator to represent the correlations in spectral space, and relies on an assembling algorithm which can be easily parallelized. The procedure takes into account any preconditioning used for the minimization, and allows an easy cycling of the variational assimilation including the definition of a preconditioning based on the forecast error covariance matrix.

MULTIPLE-TRUNCATION INCREMENTAL STRATEGIES FOR VARIATIONAL DATA ASSIMILATION

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The incremental approach provides an approximate solution to four-dimensional variational data assimilation (4D-Var) at a reasonable CPU cost. An extension of this approach is studied, namely the multiple-truncation incremental technique, and is compared to the standard and single-truncation incremental implementations of 4D-Var, using a two-dimensional barotropic vorticity equation model.
The quasi-continuous approach deals with the cut-off problem and spreads the computer requirements over time. Quasi-continuous incremental and quasi-continuous multiple-truncation incremental techniques are assessed.
The same number of iterations is specified in all the experiments. The multiple-truncation incremental technique is found to produce a good approximate analysis at a lower CPU cost, especially when the underlying flow is unstable and the background field is of poor quality. Applying the quasi-continuous approach to the incremental methods adds some benefit in terms of computer time.
The multiple-incremental technique is under implementation at Météo-France for testing purposes using the operational Arpège model.

A QUASI-GEOSTROPHIC DATA ASSIMILATION SCHEME FOR PRIMITIVE-EQUATION MODELS

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A simple method for assimilating sea-surface height and roughness into a multi-layer, primitive-equation, ocean model is introduced. Data for the roughness of the sea surface are used to estimate whether the divergence between the ocean evolution and that of the numerical model, as measured by the differences in sea-surface height, are primarily due to dissimilar wind forcing or to the chaotic dynamics of the two systems. In the former case, the differences in Ekman pumping lead to diffent vertical mass distributions, while in the latter case the dominant differences in the mass field occur by horizontal advection. The nonlinear quasi-geostrophic equations are used to quantify these changes in the water mass field. Current updates are then projected geostrophically from the surface to the bottom. The commonly used statistical methods to project surface data into the ocean are thus replaced by the deterministic quasi-geostrophic laws of ocean dynamics.
Results from (identical and non-identical) twin experiments with idealized topography are presented. The root-mean-square (rms) error in the barotropic stream function is reduced to less than 20% of that for the case with no data beeing assimilated, while the, rms errors in the deep currents are reduced to less than 30%.

TIDAL DATA ASSIMILATION FOR THE NEWFOUNDLAND AND SOUTH LABRADOR SHELVES BY A DIRECT INVERSE METHOD

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This paper describes an application of a newly developed data assimilation method, the direct inverse method, to remotely-sensed and in situ tidal data from the Newfoundland and South Labrador shelves and adjacent regions. The method seeks an explicit relationship between the interior solutions and boundary forcing via a finite element discretization of the linear 3D shallow water equations in frequency domain. The explicit relationship is then used as a general regression model to assimilate the interior observations to produce an optimized boundary forcing.
The initial application is carried out for M2 and K1 tidal constituents. The remotely-sensed data from the TOPEX/POSEIDON satellite provide information on the tidal amplitudes and phase lags over a large area (~ 1000 km × 2000 km). The in situ data include coastal tidal gauge data, offshore bottom pressure data, and moored current meter data. Constrained by more than 1400 data points distributed almost evenly in the entire domain, the optimized field of tidal elevation is believed to be highly realistic and the 3D current fields provide a high resolution representation of the flow over offshore topography and around coastal features.

OA25 Developments in weather forecasting

Convener: Gustafsson, N.
Co-Convener: Benard, P.

IMPROVING TIME INTEGRATION SCHEMES IN PREDICTION MODELS

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In an effort to find time integration methods which both improve forecasts and reduce computing time (and possibly exploit MPP architecture), we have studied a variety of techniques and show applications to some simple models. We began with a Taylor Series (TS) approach applied to the BVE (both grid and sphere), then moved to the shallow water equations (SWE) which are considerably more realistic. Since the shorter frequencies implied by gravity motions could restrict the benefits of the TS approach, we applied the SWE in the spectral domain, using an expansion in Hough modes. We split the wave spectrum into high and low frequency domains, predicting low frequencies and balancing high frequencies. For prediction efficiency, we tested the TS approach and found a significantly effective increase the basic time step. Using the SWE expanded in their Hough modes, we explored the sensitivity of predictions to the cutoff scale separating those modes which are predicted from those which are balanced, including shifting this cutoff to various frequencies. We then developed a multi-level time integration scheme, superior to the TS method, which proved very workable with the SWE, providing much more accuracy than the simple leapfrog scheme at a significantly lower computer cost. Finally, we included a zonal mean state into the SWE, generated a new set of normal modes, and integrated the SWE with these modes, separating the equations in the same fashion as the Hough mode equations described above. Results of these integrations will be presented.

PROGRESS IN SEASONAL WEATHER PREDICTION WITH A THERMODYNAMIC MODEL.

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V. M. Mendoza, A. Ruiz, E. E. Villanueva, R. Garduño, (Same address)

A long-range forecasting technique, based on a physical model that emphasizes thermodynamics is applied to the prediction of anomalies of temperature and precipitation. Seasonal forecasts are initialized with the sea surface temperature, the 700 mb temperature and the surface snow-ice conditions. Recent verifications in Mexico, for the period from February 1981 to November 1983, using a revised model, show a useful skill in the predictions, which depends mainly on the ocean temperatures. The best skill in predicting the precipitation anomalies, is obtained for the "El Niño" period especially for the summer, as has been confirmed by the recent predictions for the 1997 "El Niño" period.

FORECASTS FROM THE 1-H ASSIMILATION CYCLE IN THE 40-KM RAPID UPDATE CYCLE

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In support of different short-range forecast users including aviation and severe weather forecasting, a new version of the Rapid Update Cycle has been implemented in 1998 in the USA. This version features a 1-h intermittent assimilation cycle, as well as higher horizontal and vertical resolution and fairly advanced physics. Observation types assimilated on an hourly basis include wind profilers, RASS, boundary-layer profilers, surface stations/buoys, commercial aircraft, satellite precipitable water and satellite cloud-drift winds. The 40-km 1-h RUC continues to use an adaptive isentropic-sigma hybrid vertical coordinate, but now with 2 K isentropic spacing in much of the troposphere. Cycled variables include not just wind, temperature, and water vapor, but also mixing ratios for 5 types of hydrometeors, soil moisture and temperature at 6 levels, and snow depth and temperature. Verification shows significant improvements in this new version of the RUC over the previous 60-km 3-h cycle version, especially in the lower troposphere. A comparison of 1-wind forecasts with 3-h forecasts valid at the same time shows fairly consistent improvement for winds, a weak improvement for upper-level temperatures, no change for moisture forecasts, and slight degradation for height forecasts. These results will be explained in the context of the data assimilated and analysis and initialization procedures.

MODELING OF MESOSCALE PHENOMENA ON PARALLEL AND VECTOR COMPUTER

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The computer time required for modeling the atmospheric phenomena increas rapidly with the numbers of grid points. In order to keep the computational time reasonably short it is nesesery to use e very fast computers. Additional reduction can be achived using parallel computers. In this paper the performance of vector (Cray YMP) and parallel (Cray T3E) computer is compared using nonhydrostatic numerical model.

REPRESENTING URBAN AREAS IN NUMERICAL WEATHER PREDICTION MODELS.

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As the fraction of the World's population that live in cities continues to grow, it is becoming increasingly important to be able to provide accurate forecasts for these environments. The development of the boundary layer over a city can also initiate mesoscale flows between the urban and surrounding rural areas, as well as having important effects for pollution dispersion both inside and downwind of the city. To be able to model these effects and provide accurate forecasts for a city, urban phenomena such as the urban heat island must be represented within numerical weather prediction models.

Two schemes will be presented for the surface exchange from an urban area. The first is the traditional scheme which represents an urban surface in the same way as a bare soil surface, but with the surface properties appropriate for the urban environment. The second scheme considers the urban area as a canopy of concrete above the underlying soil. It will be shown that the canopy scheme can represent the thermal effects and evolution of the urban heat island better than the traditional bare soil scheme.

A MULTI-MODEL HYBRID APPROACH TO SEASONAL PREDICTION: OPTIMISING A PROBALISTIC FORECAST

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Forecasting seasonal mean conditions one season in advance is commonly done using sophisticated general circulation (GCM) and/or statistical models. We have performed a series of historical ensemble seasonal forecasts for the period 1969 to 1994 using the Canadian GCM and the NWP model currently used for global medium- and long-range forecasts at the Canadian Meteorological Centre. A series of statistical forecasts was produced for the same period in cross-validation mode with the two-step method proposed by Vautard et al. (1996). The geographical distribution of the skill of these models (dynamical and empirical) displays inhomogeneous inter-model differences which suggests that a hybridization of the outputs could improve the overall skill of the prediction. Here we present and illustrate a general linear regression method for blending predictions from different models in order to produce more skillful forecasts. The results in cross validation mode have shown improvement when the RMS-score was optimized and also results for an optimized percent correct score will be discussed for a probabilistic three-category forecast for surface air temperature and thickness for different seasons, lead times and variables.

SIMULATING MODEL UNCERTAINTIES IN ENSEMBLE PREDICTION

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The European Centre for Medium-Range Weather Forecasts (ECMWF) Ensemble Prediction System (EPS) is currently based on 51 non-linear integrations of a TL159L31 resolution model version, one (the 'control') from the 12Z unperturbed analysis, and 50 from the 12Z analysis perturbed along unstable directions. This design was based on the hypothesis that the medium-range numerical Weather Prediction problem is essentially an initial condition problem, and that analysis error is the main cause for forecast degradation. Recent investigations confirmed that uncertainties in the initial conditions dominate model errors, but indicated that also model error can affect forecast accuracy. Thus, at ECMWF a strategy is under investigation to simulate model uncertainties in the EPS. The ECMWF approach to simulating model uncertainties by stochastically perturbing the diabatic tendencies will be discussed, and preliminary results of the impact of parametrized model uncertainties on the ECMWF EPS statistics will be presented.

ESTIMATION OF ANISOTROPIC FORECAST ERROR CORRELATION PARAMETERS FOR THE GEOS-DAS OZONE ASSIMILATION SYSTEM

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The GEOS-DAS ozone assimilation system presently being developed at NASA's Data Assimilation Office involves explicit, parameterized observation and forecast error covariance models. The latter are based on the flow-dependent, anisotropic correlation model proposed by Riishojgaard (1997). This model assumes that the correlation between forecast errors at two locations depends not only on distance but also on the gradient of the ozone mixing ratio field. The parameters which describe this dependence can be estimated from total ozone observed-minus-forecast residuals by means of the maximum-likelihood method (Dee and da Silva, 1998). Initial results obtained with TOMS data will be presented in this talk.

Dee, D. P., and A. M. da Silva, 1998: Maximum-likelihood estimation of forecast and observation error covariance parameters. Part I: Methodology. *Submitted to Monthly Weather Review.*

Riishojgaard, L.P., 1997: A direct way of specifying flow-dependent background error correlations for meteorological analysis systems. *Tellus, in press.*

AN ADAPTIVE BUDDY CHECK FOR ON-LINE QUALITY CONTROL OF OBSERVATIONS

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The central component of the new GEOS-DAS on-line quality control system being developed at NASA's Data Assimilation Office is a buddy check, which is a test of individual suspect observations against available nearby non-suspect observations. A novel feature of this test is the fact that the error variances which are used for the quality control decisions are re-estimated on-line, following Dee (1995). As a result, the allowed tolerances for suspect observations can depend on local atmospheric conditions. The system is then better able to respond to emerging synoptic features which the forecast model has failed to predict, insofar as local observations are available to trigger the response.
In this talk we will describe the statistical framework for the adaptive buddy check, and present initial results obtained with the new system.

Dee, D. P., 1995: On-line estimation of error covariance parameters for atmospheric data assimilation. *Monthly Weather Review*, **123**, 1128-1145.

A VARIABLE RESOLUTION STRETCHED GRID DYNAMICAL CORE OF A FINITE-DIFFERENCE GCM WITH A REAL OROGRAPHY: LONG-AND-MEDIUM-TERM INTEGRATIONS

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The impact of introducing a real orographic forcing into a finite-difference GCM dynamical core is investigated. The computational noise arising from grid irregularity is reliably controlled. A portable global stretched grid is designed. The medium-range integrations are performed with fine uniform resolution of 1,0.5, and 0.25 degree over the area of interest, a rectangle over the U.S. territory, and the benchmark long-term integrations with that of 2 degree. All the grids are stretching outside the area of interest to 4 or 8 degree with the total global stretching factors ranging from 4 to 32. The stretched grid dynamical core integrations are validated against the corresponding fine uniform global resolution runs as the control ones. The results obtained for both the long-term and medium-range integrations show a striking similarity of the fields and patterns produced by the stretched grid integrations and those of the control runs over the area of interest and its large vicinity. It shows that the variable resolution stretched grid approach is a viable candidate for regional medium-to-long-term integrations. The development of the full diabatic stretched grid GCM is under way. The stretched grid GCM will be used for regional and sub-regional climate simulations, and later for data assimilation.

THE IMPACT OF DIABATIC INITIALIZATION ON THE STRATOSPHERIC DATA ASSIMILATION

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An efficient diabatic initialization is applied to the Goddard Earth Observing System (GEOS) 4-D Data Assimilation System (DAS), with a special emphasis on the impact on stratospheric fields and diagnostics. The initialization procedure is based on the application of the iterative Euler or "super-Matsuno" scheme as a highly selective filter. Within the diabatic initialization approach the model itself is used as a balancing mechanism. Only forward diabatic model integrations are used for initilization. The new 70-layer GEOS GCM extending to 0.1 hPa is used within the DAS. The diabatic initialization technique appears to be a usefull tool for improving stratospheric analyses, diagnostics, and medium-range forecasts. It controls reliably non-meteorological oscillations and spin-up effects resulting from initial imbalances. Stratospheric analysis errors are reduced by applying diabatic initialization. Initialization affects positively not only the instanteneous analyses but also the monthly mean ones and the major characteristics of the stratospheric circulation what is important for a climate DAS. The atmospheric chemistry transport experiments show improvements due to using initilized winds. Ten day stratospheric forecast scores are improved when using initialized initial conditions. The developed initialization method is computationaly efficient and easy to implement to different troposphere-stratosphere global and regional DASs.

A 3-DIMENSIONAL VARIATIONAL DATA ASSIMILATION FOR HIRLAM

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A 3-dimensional variational data assimilation (3DVAR) for the HIRLAM (High Resolution Limited Area Model) has been developed. This 3DVAR includes a background constraint and an observational constraint, both being the subject to a minimization algorithm. A weak geostrophic balance condition is applied by treating the mass field increments (temperature, logarithm of surface pressure and specific humidity) and ageostrophic wind increments as control variables. Isotropic and non-separable structure functions are modelled by means of spectral transforms in the horizontal and projection on eigenvectors of background error covariance matrices in the vertical. Observation operators have so far been developed for conventional data and a few types of satellite data. A variationally based quality control has been introduced with the aim to reject erroneous observations. A general presentation of the HIRLAM 3DVAR will be given, supplemented by single station impact studies to illustrate the structure functions.

TESTING OF AN EXPLICIT SUBGRID-SCHEME WITHIN THE DEUTSCHLAND-MODEL

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An explicit subgrid-scheme for the mesoscale has been modified and tested for the Deutschland-Model using the soil and surface physics of this model. This scheme will be described and first results will be presented. The results of simulations with and without consideration of subgrid-scale heterogeneity substantiate that the partitioning of the atmospheric radiative and moisture forcing at the surface as well as cloud and precipitation formation can significantly be affected by the subgrid-scale landuse characteristics. Compared to the use of homogeneous surface conditions within a grid cell and, hence, homogeneous precipitation, evapotranspiration and soil wetness conditions, the parameterization of subgrid-scale precipitation and evapotranspiration presented here leads to a more realistic description of hydrological processes.

A COMPARISON BETWEEN THE HIRLAM OI AND THE HIRLAM 3DVAR SYSTEMS

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The HIRLAM optimum interpolation (OI) system has been in operational use for many years in the HIRLAM member countries. In 1995, we started the development of the next generation data assimilation system. The HIRLAM 3-dimensional variational data assimilation system (3DVAR) is ready for real data experiments. In this study, an intense cyclone development case is chosen to compare the performances of the operational and the new systems. Fit to observations, fit to background fields and balance characteristcs with regard to preceeding model integrations are investigated. While the analysis increments produced by the two systems are similar to each other, the HIRLAM 3DVAR results in better balanced analyses compared to the HIRLAM OI analyses.

RIPP; A NEW FORECAST PRODUCTION SYSTEM FOR INCREASED EFFICIENCY AND AUTOMATIZATION IN SWEDEN

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The Swedish Meteorological and Hydrological Institute (SMHI) has recently modernised its observing system (OBS2000), and during spring 1997 a new Mesoscale analysis (Mesan) system has been implemented. The modernisation programme is now concentrated on the development of improved processing and communication, forecast tools and procedures (automation), and in a near future also on dissemination systems. The work will culminate in 1998 in the deployment of RiPP (Rationalization in the Production Process). One of the main components in the forecasting system is the real-time database, which includes all basic information; observations, analyses and different forecast guidance in gridded forms. In a specific forecast database special key parameters or sensible weather parameters will be monitored manually. Values in this database will be updated with information derived directly from the real-time database. The forecaster will modify and maintain the forecast database to create a certain quality of the future state of the atmosphere in the defined forecast area. A variety of forecast products will then be generated more or less automatically from these databases. The new production system will be implemented during 1998.

SIMPLIFIED VARIATIONAL DATA ASSIMILATION TECHNIQUES WITH A LIMITED AREA MODEL

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A regional weather prediction system (HIRLAM) has been modified to include a variational component in the data assimilation system. The original data analysis of the model is based on optimum interpolation (OI), the purpose of this work is to explore how variational methods may be used to improve the basic OI system. We do this by first determining forecast error structures and then use the variational technique to construct corrections to the initial state and the lateral boundary forcing which decreases the forecast error. In a few data assimilation experiments we show how a combined OI/variational system improves forecast performance compared to the original OI system. The main idea is to do the OI analysis in two steps, where the deviation between the first guess and analysis fields in the first step is used to determine a new first guess field which is used for a second OI analysis. We also find that some forecast errors can be corrected by adjusting the boundary forcing fields. In determining lateral boundary forcing corrections we see clearly that the presently used lateral boundary condition in HIRLAM is ill posed, which limits the applicability of the variational technique.

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THE PERFORMANCE OF THE HIRLAM MODEL IN THE TROPICS AND SULPHUR TRANSPORT STUDIES BASED ON ITS FORECASTS

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The high resolution limited area model HIRLAM was applied over a tropical area including India, Indonesia and the Indian Ocean. The model was run with a horizontal resolution of 0.4 times 0.4 degrees and with 31 vertical levels. A semi-implicit Eulerian time integration scheme was used and the forecasts were run without any initialization. Forecasts from the HIRLAM model were used for sulphur studies with the transport/chemical model MATCH (Mesoscale Atmospheric Transport and Chemistry modelling system). It was used to compare modelled wet- and dry deposition of anthropogenic sulphur species in India and South-East Asia with measurements performed in the region during the simulation period. The performance of the HIRLAM model, which has earlier mainly been used in the mid-latitudes of the northern hemisphere, over an area in which both the equator and part of the Himalayas were included showed up to be encouraging. A good quality of the HIRLAM forecasts is essential for successful simulations of sulphur transport and hence the results from the transport/chemical model studies give an indication of the quality of the performance of the HIRLAM model in the tropics.

ENHANCED RESOLUTION IN THE UK METEOROLOGICAL OFFICE OPERATIONAL NWP SYSTEM

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By the end of 1997 the UK Meteorological Office will upgrade the resolution of its operational global NWP forecast system from 19 to 30 vertical levels and from 90km to 60km in mid-latitudes. We will show that changing the model resolution has lead to extensive improvements in the model performance. In particular systematic errors in temperature, moisture, momentum and mass fields have all been improved. Using budget diagnostics we will discuss the physical mechanisms which have lead to these improvements. Additionally, objective and subjective verification of forecasts shows that the forecasts generated by the enhanced resolution system are typically superior to those generated at standard resolution.

Implementation of the mos technique for improved mesoscale forecasts

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The output from mesoscale version of the Unified Model taylored to Poland area (UMPL model) has been used to derive regression equations for forecasting the surface weather variables. 150 days long dependent sample for selecting predictors were verified on 30 days independent sample by a cross-validation method. Predictors were selected using the screening regression. Results, applied for such surface parameters as a maximum and minumum temperature, wind, cloud amount and probability of precipitation will be presented for selected stations from Central Europe area. The quality of the MOS results will be compared with statistics from direct model output and verified against observations.

ON DEVELOPMENTS AND PERFORMANCE OF A SITE SPECIFIC FORECAST MODEL

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The Site Specific Forecast Model (SSFM) is based on the single column version of the UKMO Unified Model, driven by output from the Mesoscale model (MES). Vertical resolution of the SSFM within the boundary layer is four times that of the MES.
The SSFM includes a fully interactive soil and surface scheme and a tile scheme to represent sub-MES gridbox surface turbulent exchange using high resolution land-use data. The impact of local orography is also taken into account.

Assessment of the performance of the SSFM was carried out over a trial period coincident with the OpenRoad season, during which forecasts of road surface temperatures and icing predictions are produced for local government authorities. The model was run for a number of locations, including OpenRoad sites, civil and military airfields and research sites. Results of the trial are presented along with comparisons between standard OpenRoad output and that obtained from coupling the UKMO Road Surface Temperature model to the SSFM.

ANY IMPROVEMENTS OR TRENDS IN THE QUALITY OF FINAL WEATHER FORECASTS ?
- Results based on verifications over the past 20 years

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The ultimate goal in the development of various forecasting techniques (NWP, nowcasting, statistical forecasting etc.) should be aimed at the improvement of the quality of final weather forecasts produced for the benefit of the society. Such potential improvements can only be discovered and measured by reliable and comprehensive verification means based on extensive and representative datasets.

The ECMWF started to produce operational NWP guidance to the weather services of its member states effectively in the early 1980s. The HIRLAM model's operational production was started in 1990. An operational real-time forecast verification system was implemented at the Finnish Meteorological Institute (FMI) in the mid 90s - the system provides instant feedback to duty forecasters of the quality of their own final weather forecasts, as well as of the quality of guidance forecasts.

Do these - or some other - milestones also show up in the verifications of final weather forecasts? Verification datasets of temperature, precipitation and cloudiness have been built up at the FMI since the late 1970s. Such topics will be covered - and questions answered - based on these data!

OA25

ON THE WIND SPEED DEPENDENCE OF MOMENTUM, SENSIBLE HEAT AND MOISTURE EXCHANGE COEFFICIENTS OVER SEA IN THE 3-D HIRLAM

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Test of the specification of exchange coefficients $C_{H,E}$ for air-sea interaction has been done in 3-d HIRLAM for some storm case studies. A new formulation of $C_{H,E} = \alpha C_D^{1/2}$ is compared with the reference version $C_{H,E} = C_D$. It was found that sensible and latent heat fluxes are smaller for the new specification. The new formulation also yields a more realistic vertical profile of temperature and moisture over sea and in coastal area.
The role of spray (surface waves break and eject spray into the atmosphere) is studied also in 3-D HIRLAM. The spray droplets evaporate and change the balance of sensible and latent heat fluxes in the marine boundary layer. The effect of the spray on the fluxes can be comparable to a direct turbulent flux at wind speed of about and above 25 m/s. The sign of the sea spray meditated fluxes depends on stratification of the marine boundary layer.

IMPLEMENTATION OF THE NONLOCAL VERTICAL DIFFUSION SCHEME BASED ON $E - \epsilon$ APPROACH IN 3-D HIRLAM

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The parameterization scheme of subgrid-scale vertical turbulent fluxes on base of the nonlocal $E - \epsilon$ approach has been developed and installed in 3-D HIRLAM. This uses two full prognostic equations for E and ϵ, including horizontal and vertical advection for E, ϵ and no mixing length assumption. A stable implicit numerical method of a Crank-Nicholson type has been developed for the E, ϵ prognostic equations in the vertical. Some case studies based on results of 36 hours weather forecasts by 31 vertical levels and 0.3° horizontal resolution HIRLAM model (versions 2.7 and 4.1) are described. The main attention in these experiments were: verification of model data against observations, the role of the advection of E, ϵ and the role of the nonlocal turbulence terms. The results of two parallel runs for a summer and winter 2-weeks period are discussed. The proposed new scheme demonstrate advantages against the first order K-theory scheme in numerical weather forecasts.

FRENCH STATIONS TEMPERATURES EMPIRICAL FORECASTING AT SEVERAL TIME SCALES USING SPACE-TIME PRICIPAL COMPONENTS.

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The Space-Time extended Principal Component (ST-PC) empirical forecasting models, as proposed by Vautard & al. (1996) are applied to Surface Air Temperature prediction over France. A wide range of time scales is investigated, from daily to seasonal. Both Sea Surface Temperatures (SST, for the larger time scales) and Atmospheric Geopotential Heights predictors (for short range as well as for long range forecasts) are considered. Predictors are filtered through Multi Channel Singular Spectrum Analysis (MSSA) with various window length, from week or less, up to year. Predictability at various time scale is systematically investigated all along the year, as well as its dependence over lead time and the MSSA window length.

The skill is also compared with that of empirical forecasts using other statistical techniques, like CCA.

NONHYDROSTATIC EXPERIMENTAL VERSION OF THE HIRLAM

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The high-resolution ($\Delta x, \Delta y$ = 11 and 5.5 km), nonhydrostatic, experimental version of the limited area model HIRLAM is in the development. The employed nonhydrostatic model is based on the complete, nonhydrostatic, pressure–coordinate equations, from which acoustic component is filtered with the help of Salmon–Smith approximation, and which is reformulated for the hybrid–sigma–coordinate case. The advantage of the model is that it maintains the existing hydrostatic version entirely unchanged, but adds an additional equation, which in essence is a Poisson equation for the nonhydrostatic geopotential height. At the long–scale limit, solutions of this equation coincide with the ordinary hydrostatic geopotential height of the hydrostatic primitive equation model. Boundary conditions for the additional equation are: the induced by the rigid surface Neumann condition at the bottom, radiative conditions at lateral boundaries and the finiteness condition at the top. The last condition yields adjusted ground pressure field, and thus, it yields the filtering of external acoustic modes.

VALIDATION OF NUMERICAL ADVECTION SCHEMES VIA SIMULATIONS OF BAROCLINICALLY UNSTABLE FLOW IN THE LABORATORY

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In developing advanced numerical models for use in weather prediction, it is essential to ensure that systematic errors in the model formulations are minimised, or at least well characterized. The verification of numerical techniques used in such models is especially difficult, however, from atmospheric observations. Laboratory experiments on rotating, baroclinically unstable flows can be carried out under well controlled conditions, and well resolved spatio-temporal measurements e.g. of velocity and temperature can be made. Furthermore, numerical simulations of such flows also require no controversial parametrizations, so that attention can be clearly focussed on validating the resolved components of the simulation. In the present work, various forms of semi-Lagrangian advection have been incorporated into a numerical model of baroclinic flow in a rotating, cylindrical annulus. Cases will be presented comparing simulations of fully 3D baroclinic flows which use semi-Lagrangian schemes for temperature and/or momentum advection with those using more conventional Eulerian schemes, and with high precision measurements of velocity, temperature and heat transport in the laboratory, with emphasis on the determination of systematic errors associated with finite resolution and the choice of numerical scheme.

FORECASTING MONTHLY PRECIPITATION ON TERRITORY OF CENTRAL ASIA USING STATISTICAL METHODS

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The forecasting methods are based on the discriminant and regression analysis. Initial predictors are the values of surface temperature and pressure in 30 correlative independente points of Northern Hemisphere. Predictants are the normalized value of monthly total precipitation of reference stations. Forecasting method is adaptive. Every time all parametrs and prognostic releshionships such as quantiles, regression eqations, discriminant functions etc are calculated taking into account recent data. Prognostic values of the monthly precipitation are given in gradations "below normal","normal" (80 120%),"above normal". The forecasts are given using both discriminant function and regression equations for each month and station. These forecasts are averaged.

The method take into account the asymmetry of probability distribution of monthly precipitation on Central Asia. For the months with the considerable asymmetry the forecasting gradation is defined using discriminant function or by regression equations calculated on the "moisture sample" with the exception of the "dry" cases

Forecasts calculated by this method are used in operational practice at Hydrometeorological Centre of Uzbekistan.

AN EFFICIENT METHOD FOR ESTIMATING THE ERROR VARIANCE OF A METEOROLOGICAL ANALYSIS

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Estimating the analysis error variance, i.e. the diagonal of the analysis error covariance matrix, is an important problem in numerical weather prediction for two reasons: (i) estimating the reduction of error variance due to the ingestion of new information (i.e. the analysis step) is a necessary link in the chain for any cycling data assimilation system; (ii) when the analysis itself is the primary product of the assimilation – e.g. in reanalysis projects – an accompanying estimate of the size of its error increases its value significantly. Modern assimilation methods, such as 3/4D-VAR, SSI, and PSAS, cannot provide an estimate of this quantity, since the analysis weights are not evaluated explicitly. The diagnostic analysis error covariance equation of the Kalman filter therefore cannot be used directly. We present an efficient algorithm for generating a conservative estimate of the diagonal of the analysis error covariance matrix. We will show that in a simple, but realistic example problem, the method is able to capture most of the physical structure of the variance reduction at a small fraction of the cost of the corresponding Kalman filter equation.

NUMERICAL MODELISATION OF STORM DYNAMICS, PRECIPITATION AND ELECTRISATION.

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We use a 1,5D axisymetric storm model to reconstruct the evolution of a Florida typical summer storm, that is its dynamical, microphysical and electrical behaviour. Every time step (4 s), the axial vertical electric field is calculated, and a lightning parametrisation based on thresholds give us the lightning flashes rate, their vertical extensions, and the dissipative effect on electrical charge densities. Our reconstruction of a Florida storm is compared to Doppler radar and 3D VHF interferometric lightning observations; the relation between the evolutions of dynamics, precipitation and lightning activity are analysed using the modelling results. The most intense electrical activity is found just after the end of the main updraft, when the large ice particles begin to fall through the charging zone of the cl This first high activity stops when the LWC in this zone becomes too low. Lightning flashes change from short, high altitude, high frequency ones to long, less frequent ones. This model is also applied to some french stormy situations.

ESTIMATING ANALYSIS ERRORS WITH THE PHYSICAL-SPACE STATISTICAL ANALYSIS SYSTEM

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A few years ago NCEP and ECMWF converted their analysis systems from an optimal interpolation (OI) scheme to 3-dimensional variational spectral statistical interpolation (3dVarSSI) schemes. One of the purposes of this change was to have a data assimilation system capable of performing global analysis, thus avoiding one of OI's major weaknesses, that is, being local due to computational requirements. In the same spirit, the NASA/Data Assimilation Office has changed its OI to the physical-space statistical analysis system (PSAS), which is a variant of the 3DvarSSI schemes, operating in physical–space instead of spectral space. Although both approaches represent an improvement over OI, contrary to OI they have the drawback of not easily allowing for an estimation of the analysis error standard deviations.
In this presentation we propose practical schemes to provide estimates of the analysis error standard deviations in the context of PSAS. All the schemes studied correspond to different truncations of the analysis error covariance matrix, or parts of it, in eigenmode space. We examine the reliability and computational feasibility of these schemes.

ON THE RELATIVE MERITS OF INCREASING MODEL RESOLUTION VS. RUNNING AN ENSEMBLE

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Comprehensive objective verification statistics for the NCEP global ensemble forecasts will be compared to those for the NCEP high resolution (T126) MRF control forecasts. Note that the generation of a 10–member T62 ensemble of forecasts require as much CPU as that of a T126 control forecast so the computational cost of the compared two forecast systems is equal. As far as the accuracy of the forecasts is concerned, the pattern anomaly correlation for the ensemble mean becomes higher than that of the high resolution control at and beyond 96, 60, and 120 hours for the Northern extratropics (NH), Southern extratropics (SH), and Tropics (TR), respectively. Accuracy alone, however, measures only one aspect of a forecast system. Distribution characteristics that address the quality of probabilistic forecasts, such as ranked probability skill score, relative operating characteristics and information content, measure the performance of forecast systems in a more complex way (evaluating accuracy as well). In these different measures the ensemble mode forecast, which is formally comparable to probabilistic forecasts that we generated from the control forecasts, show higher quality than the control at and after 24–84 (NE), 12–24 (SE) and 12 (TR) hours of integration. These results indicate that even if the accuracy of the high resolution control forecast is considerably above that of the lower resolution ensemble (as is the case in the tropics), the overall utility of the ensemble mode forecast, as indicated by the distribution measures, can be considerably higher than that of the MRF control. This is because the ensemble forecasts can reliably distinguish between more and less predictable situations (that cannot be achieved with a single control forecast).

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OA26 Will the probabilistic approach be the future for numerical weather predictions?

Convener: Buizza, R.
Co-Convener: Toth, Z.

METEOROLOGY FOR THE 1997 WORLD CHAMPIONSHIP OF ALPINE SKI

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On occasion of the World Championship, held on February 2[nd]-15[th] 1997 in Sestriere (TO-Italy), the Piemont Region provided an informative service to the organising committee, the service companies, the sport technicians and the public regarding the snow-meteorological conditions and forecasts. An operative Service from 6 a.m. to 8 p.m. granted the emission of 4 meteorological bulletins, and 2 snow condition and local avalanche bulletins per day. The weather forecasts were elaborated in collaboration with the National Electricity Board of Italy (ENEL). A preliminary study about local climatology was performed to optimally locate the new snow-meteorological stations in the area and to analyse the variability of the local parameters. The tools available at Sestriere to produce the weather prediction were the output of meteorological models (the global ECMWF model and Mephysto LAM used at higher resolution) and the wind-field rebuilt by a mass-consistent model over an orographically very complex zone. Other post-processing statistical models to forecast short term parameters (air and snow temperature, wind, relative humidity) were used over the race area after a tuning period. The satellite images and the ground stations placed on purpose, allowed to carry out an accurate service of nowcasting and monitoring of the weather. A survey of the physical surface characteristic of the snow blanket was performed several times per day while a daily stratigraphical analysis of snowpack provided sporting teams with information about the ski-run snow and the organisation with an indication to keep the ski area safe from avalanche danger and to better manage the sporting event.

ADVANCES IN THE COUPLING OF PHYSICAL PARAMETERIZATIONS WITH THE "DYNAMICS" IN A GLOBAL NWP MODEL

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The physical parameterizations in global forecast models are commonly computed separate from the dynamic equations. This is due to the diffusive nature of the mostly parabolic type equations in those parameterizations. In order to solve the dynamic equations the semi-Lagrangian advection is widely used. The accuracy of this approach depends on the choosen estimate for the trajectory calculation. The trajectory calculation of the IFS model at ECMWF is second-order accurate. However, the physical parameterizations included in the model equations are only first order accurately incorporated. Averaging the physical tendencies "along" the semi-Lagrangian trajectory a second-order accurate solution is achieved which has been implemented into the current version of the IFS at ECMWF. Results will be present showing a significant impact on both accuracy and apparent noise in the medium range. In a case study of the tropical storm Erika using a high resolution model with T639 truncation the geographical position is better represented if the second-order accurate solution is applied. Numerical noise leading to a reduction of the operationally used time-step in the IFS model is drastically reduced. Furthermore, some climate studies have been conducted to investigate the impact on the seasonal scale.

AN ECONOMICAL ALTERNATIVE TO FOUR-DIMENSIONAL VARIATIONAL ASSIMILATION

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A conceptually simple and computationally inexpensive method of performing a 4dim type of assimilation is presented. The method is tested in a simple model and shown to be efficient in reducing analysis and forecast error.
It consists of the following steps to be iterated at each analysis time: among an ensemble of forecasts compatible with the uncertainty in the initial conditions, the forecast that best approximates the available observations throughout the time interval between two analysis is used as a first guess for the following analysis. An updated ensemble is then constructed by adding and subtracting to the analized field the perturbations that have grown the fastest in the previous cycle.
The procedure is aimed at finding the state compatible with the dynamics of the model that is closest to the true state rather than forcing the model to readjust to the real data once the forecast has already diverged from the true trajectory. Furthermore, by perturbing the analysis along unstable directions it is possible to keep track of and reduce the forecast error. The method has also the advantage that in the operational mode all observations - conventional or not and at irregular time intervals - can be used to diagnose which forecast best approximates reality.

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ENSEMBLE PROPERTIES OF CUMULUS CONVECTION - SOME INFERENCES FROM STATISTICAL MECHANICS

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When developing ensemble prediction methods for probabalistic forecasting of precipitation, it is likely to be useful to have estimates of the variability within a single grid box of the numerical model. This information is not normally provided by the cumulus parameterizations used in operational models. Given the constraints on the convective clouds from the large-scale flow, elementary arguments from statistical mechanics can be used to predict the size distribution of the clouds and their typical spacing. The magnitude of the fluctuations in grid box-averaged quantities can then be predicted when the size of the grid is not much larger than the spacing between the clouds. For the simple case of quasi-equilibrium convection (constrained by the requirement that creation of convective available potential energy (CAPE) by the large-scale flow is approximately balanced by its destruction by the convection) it is shown that the distribution of cloud sizes peaks at the smallest scales, while the magnitude of the fluctuations in averaged quantities is inversely proportional to the square root of the area of the region. Some of these predictions have been verified in simulations using cumulus ensemble models.

EXISTENCE AND PREDICTABILITY QUASISTATIONARY CIRCULATION REGIMES.

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Quasistationary circulation regimes were distinguished in atmospheric circulation and used for the examination of atmospheric states and weather predictability. Here quasistationary circulation regimes (QRs) are defined as large-scale and persistent anomalies of the atmospheric flows, which are localized in the same regions and are repeated many times in the season. The extraction of regimes was carried out by means of the new method of hierarchical cluster analysis. The observation study revealed that it is impossible to present the atmospheric circulation over the whole Northern hemisphere as an alternation of the QRs. However, such sequences of the regimes really existed in two vast regions, like Atlantic-European and Pacific. The model of the atmosphere general circulation of the Institute of Numerical Mathematics (Russia) was used for an investigation of statistical and dynamical properties of the QRs. The treatment of numerical experiments has shown that an interaction between the atmosphere and ocean determines significantly both a localization and a duration of the QRs. A sensitivity of the atmosphere with respect to perturbations of initial states was considered apart for the periods of transitions between regimes and for each of regimes. singular vectors was applied for The growth rate of such perturbations turned out to be considerably less within the QRs as compared with transitional periods.

LONG-RANGE PROBABILISTIC FORECASTS IN MULTIMODEL ENSEMBLES

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In the framework of the PROVOST project, the European seasonal prediction experiment, four long-lead ensemble forecast experiments with prescribed SST have been carried out. Each experiment has been made with a different GCM: the ECMWF, ARPEGE-CLIMAT (with two different horizontal resolutions), and UKMO models, all integrated from common initial conditions. One of the possibilities of using these forecasts is to consider each model separately. A further possibility is the combination of the different models in a whole ensemble. This increases the size of the ensemble, providing a good test field for probabilistic forecasts in seasonal prediction because of the increased ability in estimating the forecast probability distribution function. Furthermore, the combination presents the advantage of taking into account the role of the model in the forecast divergence.

The skill and spread of each model in one-month lead seasonal forecasts has been verified from both a deterministic and probabilistic point of view by using the anomaly correlation coefficient and the ranked probability skill score, respectively. All of the models exhibit some skill in the seasonal range. The skill of the multimodel approach has also been evaluated and compared to results from each single model in order to assess if there is a significant gain for probabilistic forecasts in this approach.

TOWARDS INTERNALLY CONSISTENT ENSEMBLES IN NWP

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Ensemble forecasting schemes often require the selection of a relatively small number of initial conditions in a comparativiely high dimensional space. Competing approaches include selecting initial conditions which are (i) constrained to a subspace defined on dynamical grounds (*e.g.* the subspaces spanned by leading singular vectors or bred vectors), or (ii) unconstrained by the dynamics, or (iii) similar, but run under different models.

Consistency tests for constrained ensembles are presented. Formulation of constrained ensembles may depend upon the linearized dynamics (linearized about the control); internal consistency requires the linearization to be a good approximation of the nonlinear model dynamics for some given time (*e.g.* the ECMWF singular vector optimisation time of 48 hours). While it is commoly stated that this requirement is satisfied, this will depend on the model, the magnitude of the initial perturbations and the particular initial state. Results from NWP 500 hPa height forecasts are presented, demonstrating that the breakdown of linearity is often very rapid. The implications of these results are investigated and possible modifications to enable the formulation of internally consistent constrained ensembles discussed; the thermally driven rotating annulus provides a testbed.

SHORT-RANGE ENSEMBLE FORECASTING (SREF) AT NCEP/EMC

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Over the past few years ensemble prediction has come to the fore as a major element in defining the future of NWP and operational weather forecasting. It is widely agreed that ensemble based probabilities and/or measures of confidence hold the best potential for enhancing the ability to make user dependent informed decisions. This paper focuses upon development of a system and strategies for short-range (0-3 days), regional model based ensembles at NCEP. The regional models are NCEP's Eta and Regional Spectral Model (RSM). In the following we emphasize preliminary assessments of experimental runs with regard to prospective operational applications in context of the NWS "End-to-End" forecast process, where user needs and requirements are (should be) the key driver in model development and model strategies. Explicit or implicit in this discussion are reference to the basic problems, issues, etc. associated with SREF. The ultimate near term objective at NCEP/EMC is to develop a prototype short-range ensemble system, strategy, and product suites for operational implementation. The key points to be made in this talk, as demonstrated by case studies and relevant verification statistics, are: a) there are inevitable uncertainties in regional model, short-range NWP owing to the sensitivity of predictions to intrinsic uncertainties in initial conditions and model formulation, b) SREF is essential for estimating these uncertainties and provide a more complete picture than the control and even single higher-resolution runs, c) more complete information yields demonstrable enhanced operational utility, d) increased and enhanced diversity of solutions is obtained with multi-model ensembles, e) increased and enhanced utility of ensembles is achieved using higher resolution (40 km) as compared to lower resolution (80 km) models, and f) dynamically constrained perturbations ("bred modes") provide much better spread than "randomly" perturbed initial conditions.

TOWARDS BETTER INITIAL CONDITIONS: VARIATIONAL ASSIMILATION, NONLINEAR NOISE REDUCTION, AND ι-SHADOWING

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Robust prediction of nonlinear systems from uncertain initial conditions requires an ensemble forecasting approach, even if a perfect model is in hand. But how to choose the initial conditions? A variety of approaches have been delployed for reducing observational error, these include (i) variational data assimilation which assumes a perfect model, (ii) nonlinear noise reduction which assumes a recurrent system and a large observational data base, and (iii) requiring consistency between the forecast errors and observational uncertainty to detect ι-shadowing in an imperfect model. Under certain idealised conditions, variational assimilation tends to restrict initial conditions toward a local stable manifold, while nonlinear noise reduction moves observations towards a local unstable manifold. It is illustrated that neither of these conditions need be met, even in simple two dimensional dynamical systems; specifically, some noise reduction along the stable manifold is often possible via variational assimilation. Initial progress towards combining these approaches so as to produce a superior probability distribution for choosing initial conditions is illustrated in a simple dynamical system. The resulting smooth distribution still falls short of a perfect ensemble.

APPLICATION OF REGIONAL SINGULAR VECTORS TO THE ENSEMBLE PREDICTION SYSTEM

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At KNMI research is performed to create an ensemble prediction system (EPS) which is concentrated on the European area and which is optimized for a forecast period of 2-5 days. Emphasis is given to synoptic parameters like surface temperature and rainfall.
For each ensemble, 50 perturbations are constructed from regional singular vectors (T42L31 ECMWF) for a target area confined to Europe. These are integrated for 5 days with the T159L31 ECMWF model. ¿From such an ensemble a huge ensemble (~ 1000 members) can be constructed at low cost, i.e. without performing new model integrations. This is achieved by combining the 50 integrated members in such a way, that the most important nonlinear effects are taken into account.
Two data sets have been generated, a winter 96-97 set and an autumn 97 set. Each set contains about 25 ensembles.
The impact of the localized ensembles will be shown on the basis of various skill scores, reliability diagrams and Talagrand diagrams. Also the impact of the construction of huge ensembles will be discussed.
This project is in close co-operation with ECMWF.

COMPARING LONG-RANGE, STATISTICAL, DYNAMICAL AND HYBRID FORECASTS IN THE ATMOSPHERE

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At the monthly range, there is still some first kind predictability lying at the slow planetary components that can be downscaled into probability distributions of the synoptic components implying that the inferred forecast has a probabilistic value. Probabilistic forecasts, normally converted categorical forecasts, are commonly obtained by high cost ensemble forecasts. We propose a more economical method consisting on a hybrid model combining filtering tools and a dynamical one to obtain categorical forecasts. The hybridization principle is the same applied in the two-step method of Vautard et. al (1996): the extrapolation of predictable features followed by downscaling of predictand categories. Here, we compare forecast scores of terces of z500-monthly means, produced by the statistical method of Vautard et. al (1996), ensemble forecasts and our hybrid model. Validation is performed under perfect model hypothesis, over a long run of the Marshall and Molteni model (1993). For the simulated analysis (the initial conditions) we add BGMs to the observations. For the ensemble forecasts we also use the BGM technique. We build a first hybrid model where the extrapolation step of the Vautard-et-al-method is performed dynamically. The recombination with the raw categorical dynamical forecast trough use of an optimal decision rule (categorical hybridization) defines the final hybrid forecast. Ensemble generalizations of that are also produced. The hybrid models produce the same forecasting score of that of ensemble forecasts with a reduction of 4 times or more in the involved burdensome calculations. The generalization of hybrid schemes to a full probabilistic forecast is under research.

ON ENSEMBLE PREDICTION IN A LIMITED AREA

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When using ensemble prediction to investigate the predictability inside a verification domain in a limited area model (LAM), it is not enough just to perturb the initial conditions as is done for global models. This is because information from the enforced lateral boundary conditions soon will penetrate into the verification area. One objective of this work is therefore to investigate the role of the boundaries on flow-specific error growth on the mesoscale, in addition to the role of the initial conditions. We also seek to find out if there is a correlation between the spread of the ensemble members and the quality of the control forecasts, and if ensemble prediction can improve mesoscale weather forecasts. If there is a correlation between the spread of the ensemble members and the quality of the control, one would like the ensemble members to give a spread which exactly envelopes all probable developments for a given initial state with its expected uncertainty. Otherwise we would end up with more confidence in the control forecast than we should. It therefore seem reasonable to also perturb the boundaries to obtain the largest spread possible. We want to investigate which of the boundaries or the initial condition is the most important in producing this spread. To produce perturbations we use the method in use at the European Centre for Medium-Range Weather Forecasts (ECMWF), based on targeted singular vectors to produce optimal perturbations for Northern Europe and the adjacent sea-areas. The global ensemble members obtained with these perturbations will be used for both initial and boundary conditions for the limited area model run at the Norwegian Meteorological Institute (HIRLAM). Double sets of experiments will then be performed, one with perturbing both the initial and boundary conditions, and one with just perturbing the initial conditions. The period of investigation is the first 20 days of February 1997. At the time of the EGS-symposium, we will probably not be able to show significant results from the HIRLAM experiments. We will therefore show the properties of the global ensemble-runs made at ECMWF based on the targeted singular vectors.

THE FUTURE OF PRACTICAL WEATHER FORECASTING IN AN UNCERTAIN WORLD.

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Within the UKMO a fundamental shift is taking place from a deterministic to a probabilistic view of the process of creating weather forecasts. Whatever type of product the customer requires the best means of creating that product is seen as being through the use of probabilities. The forecaster can then consider a full range of possible outcomes before reaching a decision.
Weather forecasting can be viewed as a two stage process. Stage one describing the expected synoptic scale evolution and stage two the resultant weather. For the medium range both of these can be described probabilistically using the ECMWF EPS system. This paper describes how EPS products are currently used within the UKMO together with future plans for their use as part of the continuing move towards a probabilistic approach to weather forecasting.
As well as describing developments in product creation issues such as training, change management and customer awareness are discussed.

PROBABILITY FORECASTING PRODUCTS FOR THE NATIONAL METEOROLOGICAL CENTRE IN BRACKNELL

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Medium-range forecast data from ECMWF, using 51-member ensembles, are used to generate probability forecasts for a set of 21 UK stations. These forecasts, for times up to T+240, are for surface temperatures at 00Z and 12Z each day, for twelve-hour precipitation accumulations, and also for certain joint and conditional events to determine the likelihood of freezing or snow-covered roads. Probability density functions can be viewed, as well as time-series of probabilities of temperature exceeding or being less than certain values and of precipitation exceeding certain amounts. Forecasters at Bracknell are increasingly being encouraged to work in probabilistic terms, and the products have been generating favourable comments by those who have used them.
Assessment is an important part of the work, and forecasters are also given access to continually updated information on a variety of assessments of the probability forecasts. Results will be presented here for Brier Scores and for Relative Operating Characteristics (ROC), and compared with results from forecast data obtained by other means including deterministic values and period-average forecasts. On average, levels of skill remain positive out to day 10. Even if predictability is low, and the ensemble has wide spread, probability forecasts usually retain some value.

Using Nonparametric Statistics to Measure Centrality of Rainfall Distribution

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This study was carried out to develop a nonparametric statistical procedure to assess centrality of rainfall distribution. This analysis tries to provide insights on how long rainfall histories need to be to infer significantly the median as a central value. Most rainfall studies using parametric statistics advocates a need for long historical data collection. Rainfall is not normally distributed as values are greater than zero and the distribution can be highly asymmetrical. If the assumptions of normality cannot be tenable, more appropriate statistics would produce inferences more reliable. This approach reduces misinterpretation of data because of skewness, contamination or miscollected data, and small sample sizes. With so called "dirty-data", many nonparametric techniques are still appropriate. Three weather stations in different environments having long data history were selected to test if subsamples of 10 or 15 consecutive years could detect significantly ($P < .05$) the population median. Sign Test was used instead of Wilcoxon Signed-Rank Test when the population data were asymmetric ($P < .05$). In all locations, subsamples of 10 and 15 years were enough to predict the annual median rainfall ($P < .05$). The final conclusion is that subsamples of rainfall are well warranted by 10 y of data collected to predict annual median rainfall and that most of the 10 y of data collected will also predict rainfall monthly. Sometimes an unusual persistency of rainfall departure larger than 10 y may increase or decrease rainfall monthly but in a full tropical year such deviations are compensated.

WILL THE PROBABILISTIC APPROACH BE THE FUTURE FOR PREDICTIONS?

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The answer to this question depends on its understanding. So the basis of the probabilistic forecast should be correctly stated. For this I offer well-known apparatus. The classical dynamical understanding of the forecast is necessary to couple with consideration of distribution function and operations over it. This approach is the manner of the description of our limited knowledge. It changes interpretation of observation as event. The observation is a manifestation of possible events and therefore only a sequence of observations in a time (and their set in the space) gives an opportunity to build a probabilistic forecast. An elementary introduction to this new approach gives a quantum formalism apparatus. Historically, the microworld physics pioneered for the comprehension of supervisions in the limited information conditions and has entered main postulates. But the Earth climatic system is much more attractive example of irregular variability, in a centre of which the idea of a state in the probabilistic space is. With a probability a new understanding of both time and forecast comes. The nature infinity and for all that an opportunity of its laws comprehension though in a probabilistic form already is almost present of human knowledge.

PROBABILISTIC QUANTITATIVE PRECIPITATION FORECASTS (PQPF) BASED ON THE NCEP GLOBAL ENSEMBLE

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Through a number of examples we subjectively compare the performance of precipitation amount forecasts from a high resolution (T126) control prediction to that of PQPFs based on a lower (T62) resolution ensemble. It is important to note that the generation of the lower resolution ensemble requires approximately the same computer resources as running the higher resolution control. The results, supported by the evaluation of many other cases, indicate that the ensemble can extend the predictability of precipitation events by a day or two as compared to using only a high resolution control forecast. The improvement the ensemble offers is manifested in forecasts that (1) have useful information for longer lead times, (2) behave much more consistently in time, (3) have more accurate information about the spatial distribution of heavy rainfall, and (4) are associated with a flow dependent estimate of reliability. During the summer months, when model performance is generally poorer, the ensemble has less to offer. This highlights the need for further model improvements. The improvements, however, should not be sought solely through increased model resolution. An ensemble of forecasts apparently offers more benefit to the users than a higher resolution single forecast, run at the same computational cost. In the future, we plan to fit a 3-parameter Gamma distribution to derive more accurate probability distributions based on the ensemble forecasts. The forecast probability distributions will then be compared to observed precipitation distributions from the past season. This will enable us to "calibrate" the PQPFs, thus making them more reliable (i. e., make the forecast probabilities match the observed frequencies of different precipitation events over the long run).

1. GSC (Laurel, MD) at NCEP

NP1 Scaling, multifractals and nonlinear variability in geophysics

Convener: Schertzer, D.
Co-Convener: Lovejoy, S.M.

03 Scaling, multifractals and nonlinearity in oceans & atmosphere (co-sponsored by OA)

Convener: Schmitt, F.
Co-Conveners: Cahalan, R.F.; Yanovsky, V.V.

A THERMODYNAMICS OF FRACTALS BASED ON WAVELET ANALYSIS: APPLICATIONS TO ROUGH SURFACES AND SATELLITE IMAGES OF FRACTAL CLOUDS.

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We elaborate on a unified multifractal description of (2D) singular distributions, including measures and functions, based on the continuous wavelet transform. This new approach relies upon the definition of partition functions from the wavelet transform modulus maxima. We demonstrate that very much like thermodynamic functions, the generalized fractal dimensions D_q and the $f(\alpha)$ singularity spectrum can be readily determined from the scaling behavior of these partition functions. We show that this method provides a natural generalization of the classical box-counting techniques to fractal functions (e.g., the image of rough surfaces), the wavelets playing the role of "generalized oscillating boxes". We illustrate our theoretical considerations on pedagogical examples including (monofractal) fractional Brownian surfaces and multifractal counterparts obtained by low-pass power-low filtering (fractionally integrating) 2D multiplicative cascades. Then, we use this methodology to compare the multifractal properties of measured and simulated radiance fields for stratocumulus clouds at 30 m resolution in the solar (reflected) part of the electromagnetic spectrum.

Use of Magnetic Susceptibility Methods for the identification of Tsunami deposits in the Tagus estuary

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The Tagus estuary is located in the Portuguese western coast near the city of Lisbon and covers an area of approximately 320 km2. It is a high mesotidal that has been subject to several large tsunami invasions in the past, particularly at 1755 and 1531. In order to identify the sedimentary signature of the tsunami waves, the record of longer-term environmental changes of the Tagus salt marshes was studied, using environmentally-sensitive proxies to identify subtle changes of salinity, depth and temperature during the last 500 years. The analysis of vertical concentration profiles of non-anthropogenic elements indicates relatively homogeneous concentrations, in accordance with the dominant silty to clayey composition of the sediments. However, significant variations were detected for the K/Rb, La/Sm and Hf/Ta elemental ratios, probably representing variations of the sediment source. The major compositional breaks detected in the vertical profiles of these elemental pairs show some correlation with the nannoplankton vertical profiles of taxa diversity and abundance suggesting that the relative contribution of marine water also changed through time. An attempt to refine the interpretation was made, using magnetic susceptibility methods. A very detailed study of two cores taken from the estuary was made, revealing that the existence of two sediment layers, characterised by two maxima of the bulk susceptibility, clearly correlated with the geochemical and nannoplankton profiles, that were probably generated by 1755 and 1531 (AC) tsunami waves.

MATCHED VARIABILITY OF THE TEMPORAL STRUCTURE OF THE GEODYNAMICAL AND GEOPHYSICAL CHARACTERISTICS

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Atmosphere, hydrosphere and lithosphere of the Earth organize the complex multiparametrical planetary system under the outside world nfluence (solar radiation, lunar tide...). Investigation of the natural (geodyn.and geophys.) longtime series give the evidence of matched temporal structure of suitable processes. For example the variations of angular momentum of planet or length of day are not only under the influence of the orbital parameters, but under the action of global atmosphere and world ocean circulations. The result of nonlinear interaction in the ocean-atmosphere system powerfully depends on the continuously changing conditions: thus, rapid random fluctuations of meteoparameters interact with SOI in a different manner at the El Nino or La Nina phase SO or at the different seasons of the year. We pay special attention to investigation of irregular structure in the range from 40 to 100 days.

SCALING PROPERTIES OF THE SURFACE CHLOROPHYLL FIELD IN THE NORTHERN ADRIATIC

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In order to study spatial structures of two dimensional fields of surface chlorophyll in the Northern Adriatic sea, scaling analysis of chlorophyll satellite images was performed. The Nimbus-7 images processed for chlorophyll with (JRC-ESA algorithm) cover the area between Po river delta and the Istra peninsula and contain 100x100 pixels with a resolution of 1000 m. An empirical investigation of the scaling laws through R/S analysis was done over the available space scales considering zonal rows and vertical columns. The satellite data were transformed into matrices {Cij} (i, j =1,..., 100) representing the surface chlorophyll with index i oriented along parallels toward the east and j along meridians toward south. The preliminary results indicate that the Hurst exponent is larger, and, consequently, the fractal dimension is lower for winter images than for other seasons. This is possibly due to the combined effects of a varying sea productivity and of changes in the circulati! on. This also indicates that temperature changes are not the main factor controlling primary productivity in the Northern Adriatic Sea. The role of the nutrient discharged by the PO river is unclear and is to be addressed in future studies using multichanel images at higher resolution.

TURBULENCE MEASUREMENTS IN THE NEIGHBOROOHD OF A STRONG VORTEX

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Whereas most of the measurement and modeling of the energy transfers in turbulence have been done in homogenenous and isotropic geometries, most real flows are strongly inhomogeneous and anistropic. Atmospheric ones certainly are, with large scales structures in the form of larges eddies being commonly generated (tornados, hurricanes, etc.). To help describe these situations, we have studied in the laboratory the closed flow produced in the gap between two corotating disks. In this geometry, a very intense axial vortex is formed. When both disks rotate at the same rate it is stable while it undergoes violent bursting when the disks angular speeds are too different. In both cases, we have performed local velocity measurements at variable distances from the vortex structure and studied how the turbulence characteristics at small scales are influenced. We find that the velocity power spectra show a $u^2(k) \propto k^{-\alpha}$ scaling region, with α varying continuoulsy with the distance to the vortex core: starting at traditional $\alpha = 5/3$ values away from the vortex it reaches $\alpha = 2.8$ near the stable vortex, or $\alpha = 1.2$ in the unstable regime. Similarly, the intermittency (described via the structure function exponents) change with the distance to the vortex and with the flow regime. The fact that the energy transfers and the intermittency characteristics are a function of the geometry and temporal dynamics of the larges scales of the flow is of importance in regards to the theoretical and numerical modeling of real turbulent flows.

TIDAL INTERNAL WAVES IN THE TROPICAL ATLANTIC: NONSPECTRAL AND SPECTRAL APPROACHES

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A method is described for analyzing oceanic fields to determine the velocity and direction of flat wave packets comprising the tidal internal wave field. The wave field is presented as the sum of plane waves each characterized by specific velocity and direction of propagation. A new method to study wave packets is suggested based on wavelet transform. Some numerical results are presented for investigating tidal internal waves on the basis of temperature measurements at 200 m level obtained from 50 moored buoys in the tropical Atlantic. Generation of waves is caused by tidal currents flowing over uneven bottom topography. Characteristics of tidal internal waves measured in the experiment are discussed. The wave length is equal to 60 km while the direction remains quasi-stationary.

NONLINEARITIES OF 3D RADIATIVE TRANSFER, ILLUSTRATED WITH BOUNDARY-LAYER CLOUDS

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Radiative transfer —a.k.a. linear transport theory— is trivially linear with respect to the source term but fundamentally nonlinear in every other respect due to the multiplicative coupling between local scattering/absorption coefficients and radiance. Nonlinearity is stronger when multiple scattering dominates photon transport, as is the case in boundary-layer cloud systems. We survey a hierarchy of old and new approaches to radiation transport in finite *variable* optical media modeling cloud systems, broken or not, with an emphasis on treatment of nonlinearity. Ordered by increasing level of flexibility in variability model and/or numerical accuracy, we have:

- standard plane-parallel cloud models, allowing at best a vertical stratification;
- popular linear combinations of the above, according to "cloudy/clear" fractions;
- "stochastic" radiative transfer in binary mixtures, using simple closure schemes;
- nonlinear averaging procedure in the Independent Pixel Approximation (IPA);
- smoothing the IPA field in the Nonlocal Independent Pixel Approximation (NIPA);
- 3D photon-diffusion theory, (almost) analogous to flow in a porous medium;
- numerical 3D radiative transfer, using Monte Carlo and grid-based methods.

To date, only the first two entries have been applied operationally, mostly in remote-sensing and energy-budget applications respectively. We present in closed form a new result for general 3D diffusion theory that underscores the nonlinear coupling at hand. It relates the systematic bias in albedo caused by variability to the spatial correlations in the extinction field and vertical component of the radiative flux-vector field.

Cloud scaling properties and cloud parameterization in the ECMWF Forecast Model.

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Cloud liquid and cloud fraction variability is studied as a function of horizontal scale in the ECMWF forecast model during several 10-day runs at the highest available model resolution, which is presently improving from 60 km (T213) down to 20 km (T600). At these higher resolutions, model plane-parallel albedo biases are reduced, so that models may be tuned to have larger, and more realistic, cloud liquid water amounts. However, the distribution of cloud liquid -within- each gridbox depends on ad hoc asssumptions of cloud 'overlap' which are not necessarily consistent with observed scaling properties, or even with scaling properties produced by the model at larger scales. To study the larger-scale cloud properties, ten locations on the Earth are chosen to coincide with locations having considerable surface data available for validation, and representing a variety of climatic regimes. Scaling exponents are determined from a range of scales down to model resolution, and are re-computed every three hours, separately for low, medium and high clouds, as well as column-integrated cloudiness. Cloud variability fluctuates in time, due to diurnal, synoptic and other processes, but scaling exponents are found to be relatively stable. Various approaches are considered for applying computed cloud scaling to subgrid cloud distributions, beyond simple random or maximal overlap now in common use. Considerably more work is needed to compare model cloud scaling with observations, and this will be aided by not only by increased availability of high-resolution surface, aircraft and satellite data, but also by the increasing resolution of global models.

ANALYSIS OF RADIOBRIGHTNESS TEMPERATURE FIELD OVER TROPICAL CYCLONE

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It is described the results of data processing for radiobrightness temperature fields over tropical cyclone at the square of (1000 x 1000) km. The correlation function, scaling exponents and singularities spectrum are calculated. A some pecularity of structural functions (SF) usage to analysis of radiobrightness temperature fields are discussed and the analytical approximation of SF dependences is given. The existence of inertial range with the power law spectrum is shown. The comparison with scaling of background fields (outside typhoons) is made.

UNIVERSAL MULFIFRACTAL ANALYSIS OF GROUND LEVEL PARTICLE DISTRIBUTIONS FROM EXTENDED AIR SHOWERS

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High-energy interactions of gammas and protons with the earth atmosphere have been simulated by means of the CORSIKA-4.50 Monte Carlo code, and the secondary-particle density distributions in the resulting Extended Air Shower. at ground level, have been studied. The fluctuations seen in these distributions show – after that a deconvolution from a white noise component is performed – features typical of a 1/f noise. The sample is then analyzed in order to study its scaling behaviour, which is eventually parametrized by means of an Universal Multifractal approach.

DESCRIPTION OF NONLINEAR TRIAD INTERACTIONS IN FLUID DYNAMICS USING TRILINEAR COORDINATES

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Traditionally the nonlinear transfer of kinetic energy between orthogonal modes in fluid dynamics has been described by a kind of convolution of Fourier coefficients, known as 'triad interaction', T_{lmn}. Triad interaction between wavenumbers n, m and l is known to be constrained by a 'detailed conservation' theorem:

$$T_{lmn} + T_{mnl} + T_{nlm} = 0.$$

There have been few applications of triads to observed geophysical flows. Recently Iima and Toh have generalized the triad description, in the case of incompressible flow, from Fourier to arbitrary orthogonal decompositions.
This presentation will introduce the use of 'trilinear coordinates'

$$\begin{aligned} T_{lmn} &= -y, \\ T_{mnl} &= 2^{-1}\left(y + 3^{1/2}x\right), \\ T_{nlm} &= 2^{-1}\left(y - 3^{1/2}x\right), \end{aligned} \qquad \begin{aligned} x &\equiv 3^{-1/2}\left(T_{mnl} - T_{nlm}\right). \\ y &\equiv -T_{lmn}. \end{aligned}$$

to depict in *two* dimensions (x, y), triad interactions between *three* modes. Examples will be presented of triad interactions between orthonormal wavelet modes, computed from NMC-analyzed atmospheric winds during blocked and zonal climate states, and compared with Fourier results.

SPECTRAL ANALYSIS OF RADIATIVE FLUX OF HETEROGENEOUS CLOUDS

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Cahalan et al. (1994) proposed the Independent Pixel Approximation to realise a fast estimation of area-averaged radiative fluxes of inhomogeneous clouds. The basic idea of the nonlocal Independent Pixel Approximation proposed by Marshak et al. (1996) is quite similar to that of the IPA, except that the NIPA may be applied to a horizontal scale of averaging comparable to the mean free path of photons. From the point of view of spectral analysis, the estimation of area-averaged radiative fluxes based on the IPA and NIPA is justified by radiative filtering of the IPA radiative fluxes at a horizontal scale comparable to the mean free path of photons. This implies a break in the spectral slope of spectra computed from the fluctuations of reflectance of heterogeneous clouds.
The present study aims to study spectral characteristics of the reflectance, transmittance and absorptance of absorbing heterogeneous clouds for different incidence angles of radiation. It is revealed that spectral characteristics of the radiative fluxes are significantly influenced by the single scattering albedo as well as by the incidence angle of radiation. If the radiative filtering dominates at horizontal scale smaller than the mean free path of photons, there is a re-distribution of filtered energy at horizontal scales slightly larger than this mean free path. This re-distribution phenomenon becomes more important as the single scattering albedo decreases, which implies that the spectral slope of reflectance spectra of heterogeneous clouds differs significantly from that of the IPA. Another important point concerns the phase shift between the reflectance and transmittance. These spectral behaviours of radiative fluxes result from the difference of cloud heterogeneity effects on the scattering and absorption.

MULTIFRACTAL AND CHAOTIC ANALYSIS OF ATMOSPHERIC TIME SERIES

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The aim of this study is to provide a complete characterization of the integrated reflectivity, liquid water content (LWC) and water vapor content of stratocumulus clouds and as a result to possibly reveal some of the peculiarities of their internal structure. A recently proposed multifractal approach [1] is employed for analysis of the real world atmospheric data. The approach is based on the nonlinearity found in natural phenomena and includes an estimation of nonstationarity and intermittency of the fields. The scale invariant properties are revealed by studying the structure functions of arbitrary order whereas the degree of intermittency is evaluated by singular measures analysis. The results are summarized on a 'bifractal plane'. The LWC data parametrization is in good agreement with the previously reported results [1]. To investigate a possible chaotic behavior the following standard test steps are performed: 1) phase-space reconstruction of the time series using the time delay approach; a first minimum position of the autocovariance function is taken into account; 2) determination of minimal embedding dimension via correlation dimension stabilization.

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UNSTABLE PERIODIC ORBITS AND ATTRACTORS OF NONLINEAR DYNAMICAL MODELS.

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Numerical method for detection of unstable periodic orbits on attractors of nonlinear dynamical systems is proposed. This method requires the similar techniques as the data assimilation does. This fact facilitates its implementation for geophysical models.
Some low-period orbits of the Lorenz model and the barotropic ocean model have been calculated explicitely. The orbits encoding and application of symbolic dynamics is used to classify and identify the detected orbits and find the whole set of fundamental cycles. Application of the cycle expansion theory to the fundamental cycles set allows to approximate some attractor characteristics difficult to calculate directly.

QUANTIFICATION OF MULTIFRACTAL DIFFUSION

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Diffusion is one of the key-mechanism in geophysics (pollutant dispersion, radiative transfer,...) as well as for their interaction with biology (predator-prey systems). Geophysical media being extremely inhomogenous, we consider diffusion in multifractal media.
We first recall the limitation of classical methods based on the scaling law of r.m.s distance traveled by particles, as well as the drastic difference between physical time and the number of steps. Indeed, we showed that the exponent of the former misses the anomalousity of the diffusion, with the only exception of monodimensional media, whereas the exponent of the latter is rather spurious.
We show that the anomalousity of the walk can be multifractaly quantified with the help of the hierarchy of the trace-moments of the walks. We test these observables on numerical simulations.

ONE POSSIBLE MECHANISM OF ELECTRIC FIELD SCALING IN A THUNDERSTORM CELL

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It is well known that the large scale electric field and space charge are forming in thunderstorms. But the origin of small stratification is purely investigated now. To understand it, we take into account that charge tranfered per collision (between hydrometeor and small water drop, e.g.) depends on external electric field, charges on the particles and their velocities. We have designed the system of equations which is composed of hydrodynamic equations, movement and Poisson one. Such a forth flow system (large and small cloud particles and ions) has been investigated and examined in thunderstorm cell. The specific flow instability - charging instability, connected with charge transfer mechanism (inductive or noninductive) has been investigated. We have obtained increments and characteristic wave numbers for this unstable waves for the initial, development and dissipation stages of the thunderstorm cell. Our results are in a good agreement with the data of electric field soundings in storms (*Marshall and Rust, Saunders*). According this data, there are many of the small scale field and charge variations on the background of large scale $\sim 800 - 2500$ meters field. The magnitude of the first one can increase the breakdown field. And in this case charging instability can play the principal role in the formation of compact discharge cells ($\sim$ 30 - 150 meters) in the thunderstorm cloud.

SCALING OF THE NATURAL VARIABILITY OF THE ATMOSPHERE-OCEAN SYSTEM

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We present the power spectra of instrumental temperature data from the Global Summary of day database from time scales of 1 day to 100 years. Maritime stations exhibit power spectra proportional to $f^{-\frac{1}{2}}$. Continental stations exhibit a $f^{-\frac{1}{2}}$ spectrum up to frequencies of f =1/(1 month) and a $f^{-\frac{3}{2}}$ spectrum at higher frequencies. We interpret these observations in terms of the turbulent diffusion of heat energy vertically in the atmosphere and ocean. A stochastic term is included to model convective instabilities in the atmosphere that randomly advect heat up or down in the atmosphere. The difference between maritime and continental stations results from the coupling of maritime air masses to both the atmosphere above and the ocean below while continental air masses couple only to the atmosphere above with the land acting as an insulating boundary condition. The transition from a continental-type spectrum to a maritime-type spectrum is investigated by averaging spectra from all stations in the database in 2°x2° grid squares. Differences in the spectra as a function of geography and distance from the ocean are investigated. The crossover time scales from the $f^{-\frac{1}{2}}$ to a $f^{-\frac{3}{2}}$ spectra in continental spectra are used to infer the geographic variation of time scales of thermal exchange between continental air masses and oceans.

EXPERIMENTAL MHD STUDY OF A LIQUIDE GALLIUM FLOW AT MODERATE MAGNETIC REYNOLDS NUMBERS

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We study the statistical properties of magnetic field fluctuations generated, in the presence of an externally imposed field, by a swirling flow of liquid Gallium. The flow is produced in the gap between two coaxial counter rotating disks. Kinetic Reynodls numbers $R_e = 10^7$ and magnetic Reynolds numbers up to $R_m = 15$ are reached. The imposed magnetic field B_0 is weak and Lorents forces do not react unto the flow. The magnetic fluctuations b are measured inside the flow using a local Hall effect probe. Its power spectra display a $b^2(k) \propto k^{-11/3}$ scaling region, as can be predicted from Kolmogorov's turbulence model. We also observe that the dissipative scale for the magnetic fluctuations is much smaller than that of the velocity fluctuations, in agreement with the very small value of the magnetic Prandtl number of liquid metals. As a result the dynamics of the magnetic field is concentrated in the large scales of the flow. For a given value and orientation of B_0, we have measured the mean value $< b >$ of the field induced by the (large scale) velocity gradients in the flow. At small R_m one finds $< b > /B_0 \propto R_m$ as is well known. For higher values of the magnetic Reynolds number, we have observed non linear effects whith $< b > /B_0$ growing as R_m^2. Interpolation of these measurements predict a critical magnetic Reynolds number $R_m \sim 30$ for the onset of dynamo action in this flow.

A NUMERICAL INVESTIGATION OF SOME SCALING PROPERTIES OF ATHMOSPHERIC TURBULENCE

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The time series representing the velocity components of atmospheric turbulence has been processed numerically. Two data sets were used. The first one was recorded at Zimlyanskaya steppe, over the flat ground. The second data set was recorded in Moscow city, near the big buildings.
The covariances, cross-covariances and power spectrum are presented. The vector delay reconstruction technique was used for fractal dimension measurements. The numerical estimation of Levy index also has been performed.

GENERATION OF HETEROGENEOUS CLOUDS BASED ON MORPHOLOGICAL ANALYSIS AND THEIR EFFECTIVE RADIATIVE PROPERTIES

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Most of recent studies on radiative properties of inhomogeneous clouds are based on the inhomogeneous clouds generated with the bounded cascade model proposed by Cahalan et al. (1994) and Marshak et al. (1994). In spite of the fact that the bounded cascade model can duplicate some statistical characteristics of natural inhomogeneous clouds, it has a drawback to generate clouds whose heterogeneity at large horizontal scale is conditioned entirely by first steps of cascades. So, there is a need to develop methods without such drawback, which may generate heterogeneous clouds having the same characteristics as those observed of natural clouds.
In this paper, we develop a method of heterogeneous cloud generation based on the morphological analysis. This method can generate horizontal fluctuations having the almost same density probability function and spectral slope. Furthermore, the generated heterogeneity has the same morphological spectra as the original fluctuations. We tested the method for various types of fluctuations, in particular those generated with the bounded cascade model.
The radiative properties of heterogeneous clouds generated with this method are compared with those determined for the bounded cascade heterogeneous clouds. This comparison shows these two types of clouds have the same area-averaged radiative properties. Based on these results, we discuss effects of cloud heterogeneity of different types on the area-averaged radiative properties and try to define heterogeneity parameters pertinent to the radiative transfer in heterogeneous clouds.

QUASI-SPONTANEOUS VARIATIONS OF PHYSICAL PARAMETERS

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Spontaneous chaotic fluctuations are inherent for complex nonlinear unstable dissipative systems especially when spatio- temporal intermittance of chaos and order occur and the system passes through consequence of bifurkations. Prognosis of development for such system is very difficult and uncertain, as the system can be influenced by extremely weak signal, but if the last one is correctly organized it opens the principal possibility of so called informational correction, management and control of the system. Speaking about spontaneous variations (SV) of physical parameters we pay also attention to relatively simple systems (resistor, filament of torsion pendulum, crystal of quartz etc.), for which we expect stable physical parameters under stabilized external conditions: temperature, pressure, moisture, EM-radiation etc. But the variations of physical parameters nevertheless are observed and their spectrum near to 1/f law. The synchronism of SV in distant points and correlation with Solar activity give evidence that the phenomenon is not purely spontaneous but rather quasi-spontaneous, being induced by some yet not identified external agent.

MULTIFRACTAL ANALYSIS OF 1D AND 2D CLOUD DATA, THE "WAVELET TRANSFORM MODULUS MAXIMA" APPROACH

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In physics and applied sciences, one is often faced with the problem of characterizing very irregular functions. Examples range from plots of various types of random walk (e.g., Brownian signals) to financial or medical time-series, turbulent signals from wind-tunnel or atmospheric studies, etc. Wavelet analysis, a general framework for analyzing signals in space and scale, has been described as a "mathematical microscope" and is well-adapted to reveal the hierarchy governing the spatial distribution of singularities in multifractal measures. The Wavelet Transform Modulus Maxima (WTMM) method is a more recent development. It is based on the continuous wavelet transform and enables us to generalize multifractal formalism to all types of singular processes, i.e., functions as well as measures. With the appropriate choice of analyzing wavelet, it includes standard box-counting and structure-function methods. The WTMM method has been tested on a variety of pedagogical examples and successfully applied to numerical and experimental data from various domains: turbulent velocity, DNA sequences, DLA clusters, etc. After presenting tutorial examples in 1D, we show results for atmospheric liquid water path (retrieved from passive microwave radiometry at the ARM site in Oklahoma) that demonstrate its strong multifractality. We also describe a 2D generalization of WTMM methodology and apply it to high-resolution LANDSAT images of clouds.

TURBULENCE PARAMETRIZATION USING FRACTAL SYNTHETIC FIELDS

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Turbulent fields that are encountered in many geophysical applications have geometric properties that are better described in terms of fractals. This talk presents a new way to express the subgrid stress tensor that arises in Large Eddy Simulation (LES) of turbulent flows by means of synthetic fractal subgrid-scale fields. First, the relevant matematical tool is reviewed. Next, the model is applied to a simple 1D scenario, Burgers equation with a stocastic forcing. Then, the extension to the 3D case is derived, which is used to formulate a subgrid closure. The model is applied to both steady and decaying isotropic turbulence. We find that the assumption of fractality *per sè* is not enough to yield physically meaningful results, and explore several variants of the model in which the rules to generate the synthetic field explicitly incorporate the condition that energy dissipation take place. Good results are obtained only once the fractal dimension is allowed to vary in different eigendirections of the resolved rate of strain tensor as to (nearly) maximize energy dissipation.

BEYOND THE MULTIFRACTAL PHENOMENOLOGY OF GEOPHYSICS: DYNAMICS AND (REVISITED) RENORMALIZATION

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A large class of multifractal models, often called Fractionally Integrated Fluxes (FIF) models, had been developed for modeling of geophysical intermittent fields. Their *static* version have become rather popular for the last ten years for the simulation of contaminants, clouds, rain, topography, etc., whereas their *dynamic* extension is rather recent.
We show that FIF models have a "renormalized viscosity/renormalized forcing" structure: both terms correspond to the relevant contributions from other scales to the evolution of a given scale in a renormalization procedure. However, contrary to a standard renormalization (DIA, RNG...), the renormalized forcing is far from being quasi-gaussian and the corresponding models do yield wild probability distributions, i.e. strong intermittency.
We therefore revisit renormalization techniques and obtain intermittent models built directly on the structures of the generating equations and not only on their scale invariance.

SELF-ORGANIZED CRITICALITY : A SIGNATURE OF QUANTUMLIKE MECHANICS IN ATMOSPHERIC FLOWS

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The spontaneous organization of selfsimilar (fractal) space-time fluctuation patterns generic to dynamical systems in nature is identified as self-organized criticality(Bak et.al.1988: Phys.Rev.A.38,364). Atmospheric flows exhibit self-organized criticality manifested as the fractal geometry to the global cloud cover pattern concomitant with inverse power law form for power spectra of temporal fluctuations. Mary Selvam(1990:Can.J.Phys.68,831) and Mary Selvam et.al.(1992:Int'l J.Climatology 12,137)have proposed a non-deterministic cell dynamical system model for atmospheric flows which predicts the observed self-organized criticality as a direct consequence of quantumlike mechanics governing flow dynamics. The model predictions are as follows.(1)Atmospheric flows follow an overall logarithmic spiral trajectory with the quasiperiodic Penrose tiling pattern for the internal structure.(2)Traditional power spectral analyses of such spiral flow structures will reveal a continuum of eddies with embedded dominant wavebands.(3)The power spectra follow the universal inverse powerlaw form of the statistical normal distribution,thereby providing unique quantification for observed self-organised criticality. (4)Climate change induced by man-made greenhouse gas related atmospheric warming will result in intensification of fluctuations of all scales seen immediately in high frequency fluctuations.

A SCALE-BY-SCALE VALIDATION OF CONTINUOUS MULTIFRACTAL MODELS IN TURBULENCE

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We consider two continuous (in scale) cascade models: log-Poisson and log-Lévy (a special case of which is the log-normal model). The usual way to validate cascade models is to estimate $\zeta(q)$ defined as $<|\Delta V_l|^q> = C_q l^{\zeta(q)}$. This corresponds first to estimate some scale invariant function, and then to use it to estimate the parameters of cascade models. This is useful to eliminate e.g. the log-normal model, but not precise enough to clearly show which one from log-Poisson or log-Lévy models is closer to data: these two models provide excellent fits of empirical $\zeta(q)$ curves up to high order of moment (of about 7).

We therefore propose another approach, which consists in studying the statistics scale-by-scale: we first estimate the parameters of models at a given scale and then consider the scale-dependence of these parameters. This procedure can be done much more precisely than previously, because it is done for a fixed scale, and no more needs a straight-line fit in log-log using least square method. This corresponds to estimate $\Phi_l(q) = \log <|\Delta V_l|^q>$, the second Laplace characteristic function of the generator $g_l = \log|\Delta V_l|$ of the velocity shear (it is also called cumulant generating function). Then we precisely estimate the range of values of q for which log-Poisson and log-Lévy models are fitting the empirical data: this clearly shows the validity of the log-Lévy model (with $\alpha = 1.5 \pm 0.1$) as opposed to the log-Poisson model which has no scale-invariant parameter.

TIDALLY INDUCED HETEROGENEITY IN DIFFERENT HYDRODYNAMIC CONDITIONS: A MULTIFRACTAL ANALYSIS

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The multifractal properties of temperature, salinity, *in vivo* fluorescence (i.e. estimate of phytoplankton biomass) and nutrient concentration recorded for time scale of 1 sec to 1 hr were investigated in different hydrodynamical regimes related to tidal forcing. Power spectrum and probability distribution analyses indicate that temperature, salinity and nitrites fields are scaling over the whole range of scales whereas the temporal scaling regime was approximately 1-25 sec for the fluorescence field, and that the whole data were hyperbolically intermittent. The analyses of statistical moments show that variability of these different parameters were well characterized by a multiscaling behavior for low order moments. Moreover, the characteristic spectral exponent β, the first order scaling exponent of the structure functions $\zeta(1) = H$, as well as the basic universal multifractal parameter C_1 determined using the Double Trace Moment analysis technique clearly showed a tidal variability. These results showed that the structuration of temperature, salinity, phytoplankton biomass and nutrient concentration can then be viewed as the result of multiplicative processes, wholly dependent on the hydrodynamical conditions associated with tidal cycle.

MULTIFRACTAL ANALYSIS OF CLOUDS FROM 5000KM TO 50CM AND THE DEMISE OF THE MESOSCALE GAP

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The standard model of the atmosphere assumes that the small and large scales are isotropic homogeneous 3-D and 2-D turbulences respectively, with these two qualitatively different regimes seperated by a meso-scale "gap" in the spectrum at scales of roughly 10km (the vertical pressure scale). Identifying the 2-D turbulence part with the "weather" is the classical justification for the lack of explicit treatment of subgrid processes in numerical weather models. We analyzed over a thousand visible and infra red images from geostationary (GMS), polar orbiting (NOAA 12, 14, SPOT) satellites as well as ground based images (roughly 100 times more data than that used on any comparable study) to study the scaling properties of clouds over the range 5000km to ≈50cm. As predicted by the unified scaling model, the radiance fields are indeed very close to what is expected for universal multifractals. In the latter, the infinite hierarchy of exponents (e.g. dimensions/codimensions) is described by only three universal exponents (H, C_1, α): the nonconservation exponent (H) of the mean field; the mean singularity (C_1) and (Levy) index of multifractality. The clustering over the values of C_1, α near $C_1 \approx 0.075$, $\alpha \approx 1.88$ indicates that the probability distributions/statistical moments of the generator have nearly identical scaling properties over the range 1-5000km. Finally, we compare these results with those of ground based photography, which again shows quantitatively similar scaling.

NONDIFFUSIVE SCATTERING STATISTICS IN UNIVERSAL MULTIFRACTAL CLOUDS:

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Recently, we developed a multifractal scattering formalism for radiative transfer in multifractal clouds in which the (nondimensional) extinction coefficient κ takes the place of the scaling parameter λ. This allowed us to renormalize the multifractal cloud defining an "effective" extinction coefficient $\kappa_{eff} \approx \kappa^{(1-K'(0))^{-1}}$ (Note, K'(0)<0; K(q) is the moment scaling exponent for cloud density); this result requires only analyticity at q=0.

We have now extended this to certain nonanalytic cases (with exponent of nonalayticity $1 \le \alpha < 2$; corresponding to universal multifractals), obtaining $\kappa_{eff} \approx (\log \kappa)^{\frac{\alpha}{2}}$. Due to large "Levy holes", photons travel extremely far - even in clouds which are on average very optically thick. The nondiffusive nature of this scattering can be quantified by comparing the most probable distance with the R.M.S. distance; these quantities are nearly equal in thick clouds with analytic K(q) at q=0, but in these universal multifractal clouds, they vary as $\kappa^{-(1+C_1/(\alpha-1))^{-1}}$ and $(\log \kappa)^{-\frac{\alpha}{2}}$ respectively. Note that these occasional long distance scatters will - in the presence of water vapour - significantly contribute to anomalous cloud absorption.

A METHOD TO IDENTIFY MORPHOLOGY AND SPATIAL SCALE OF CLOUD SYSTEMS USING FRACTAL BOX-COUNTING DIMENSIONS

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Mesoscale cloud systems are followed in satellite infrared images during their life cycle over the equatorial Pacific Ocean. Using a technique of cloud classification based on IR and VIS radiance, convective tops are separated from thick anvil. Box-counting dimension (Db), graph dimension (Dg) and fraction of clouds (Ac) are computed for the images of systems and convective tops during their life cycle. Through the application of Principal Components Analysis using as variables Ac, Db, Dg for 216 images, eight patterns of clouds have been separated according to their spatial scale and morphology defined by multifractal properties. Time evolution of these patterns are studied for 68 life cycles of cloud systems. Frequency of patterns and how these are related to phase and duration of life cycles are investigated. Predominance and transition of patterns for anvils and convective tops are also shown. Time evolution of structural characteristics related to size, intensity and spatial distrubution of cells are compared to the observed change in morphology. It is shown that, in general, patterns of systems and embedded convective tops are similar, but for most cases convective tops have larger ratio perimeter/area.

NH2 Meteorological and hydrological hazards (joint with HS)

03 Flood hazards and flood risk: regional analysis of extremes (co-sponsored by OA)

Convener: Bois, P.
Co-Convener: Oancea, V.

FLOOD PREDETERMINATION MODEL BASED ON HOURLY RAINFALLS STOCHASTIC GENERATION

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For the needs of hydrological studies, a hourly rainfall stochastic model has been developed to be coupled with a rainfall runoff conversion model. Thus, many hourly flood scenarios are obtained by simulation on very long periods. The hourly rainfall model has been improved and tested on a large area, 49 raingauges located on the French Mediterranean seaboard. With the rainfall generated, flow time events are simulated with the conceptual spatially-lumped model GR3H. The method has been tested on 17 watersheds on the studied area and gives good results. The advantage of this approach is to obtain rainfall and runoff temporal information. Different realistic flood scenarios, which occurrence is obtained by simulation, are used instead of a unique design flood. Moreover, the large use of rainfall information and the rainfall runoff conversion modelling seems to give a more important stability to this approach rather than the classical statistic methods.

THE FREQUENCY OF LOW MAGNITUDE FLOODS: A STUDY OF THE RELIABILITY OF THE ANNUAL MAXIMUM SERIES METHOD

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The analysis of annual maximum series is a standard procedure used to establish the recurrence of floods of a given magnitude; however, it ignores subordinate peaks of some years which exceed the lowest maxima of the series, and thus underestimates the occurrence of low magnitude floods. To determine the reliability of the AMS method, frequency distributions of low magnitude floods derived either from annual maxima (AMS) or from all peaks exceeding a selected threshold discharge are compared for a set of gauging stations located in the upper Vistula River drainage basin, but on streams with somewhat different flood regime and a range of catchment areas. A considerable variation in the mutual relation of the two series exists among the stations despite their close proximity. The high variation remains even when the recurrence intervals of the AMS are transformed to their equivalents in the partial duration series by means of the Langbein relationship. The divergence between the AMS and PDS increases with growing variability of the annual maximum discharges, and generally, the underestimation of flood discharges of a given recurrence interval by the AMS is high for streams with a flashy regime, but low for streams with more uniform run-off. This study shows that the actual flood magnitudes for a given probability cannot be satisfactorily obtained by means of a simple transformation of the recurrence interval for known AMS discharges. Therefore, despite the long tradition of using the AMS method, it is recommended that the partial duration series method should be employed when evaluating the occurrence of low magnitude floods.

A METHODOLOGY FOR THE ESTIMATION OF THE IMPACTS OF CLIMATE CHANGE UPON FLOOD FREQUENCY (WITH UNCERTAINTY)

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A modelling strategy, appropriate to the assessment of the impacts of climate change upon flood frequencies within an uncertainty framework, is introduced. The methodology couples a stochastic rainfall generator with the frequency version of TOPMODEL for the purposes of flood frequency estimation. Following constraint of *non-behavioural* rainfall realisations through the application of an observed/simulated sum of absolute errors criterion (based upon duration class annual maximum rainfalls), multiple realisations of potential annual maximum flood frequency curves are produced through the use of continuous simulation and Monte Carlo techniques. Further constraint of these realisations is then achieved via an observed/simulated flood peak sum of absolute errors measure, low flow conditioning, and calibration/validation for continuous rainfall/runoff modelling. Uncertainty in the flood frequency predictions is estimated using these *behavioural* realisations within the Generalised Likelihood Uncertainty Estimation (GLUE) framework. Example applications are provided for assumed "stationary" conditions.

LAST YEAR SUMMER FLOODS IN MORAVIA: WHAT IS THE FUTURE?

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Dramatic floods occurred in Central Europe in summer 1997, Czech Republic being afflicted especially in its eastern part - Moravia. Predictive approach when modeling flood recurrence may be helpful in flood management. Summer floods are typical by saturated catchment due to long-lasting heavy precipitation followed by an extreme rainfall. We analyzed temporal variability of precipitation time-series by fractal analysis, revealing persistent fractional noise with dimensions of 1.3-1.4. Precipitation appears to be a random small amplitude fluctuation superposed on a background controlled by more regular quasi-cycles. While the individual up-down runs last 3-5 years, the persistent trends may take more than 15-30 years. The precipitation character in Moravia, being declining with a rate of 2-5 mm/yr during the past 30-35 years, changed suddenly to the opposite tendency following the dry period of 1992-94. We modelled precipitation fluctuations with the Mandelbrot's fast fractional Gaussian noise tecnique. Simulations were used for stochastic prediction of the precipitation trends causing summer floods. Our results seem to give evidence that higher precipitation in the last years is not a sort of provisional run but belongs to a persistent trend.

REGIONAL INCREASE OF WINTER FLOODS IN SOUTHWEST GERMANY CAUSED BY ATMOSPHERIC CIRCULATION CHANGES

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Instationarity in the time series of annual peak flow will be demonstrated for the Enz River Basin/Black Forest (A = 1 477 km^2), the upper Danube (A = 1 320 km^2), and the Nahe River Basin (A = 2 382 km^2) in Southwest Germany. The reason for this is a dramatically increase in frequency and persistence of the large scale atmospheric circulation type "West cyclonic" (Wz) for the wintermonths (Dec.-Feb.). During the observation period (1926-1997) nearly all extreme floods including the floods of Feb. 1990, Dec. 1993, and Jan. 1995 for all three Basins have been caused by weather type "Wz" during winter. Nonparametric tests show that instationarity starts for the winter-Wz-frequencies and the annual peak flows of the ENZ River, the Nahe River, and the upper Danube Basin in the period of 1972 -1977. By this a shift to an increased flood risk will be demonstrated for the three river basins. Instationarity of the peakflows is caused by a significant increase of winter precipitation which itself is caused by changes of the atmospheric circulation. This leads to the HYPOTHESIS: "If the frequency and persistence of the circulation type "Wz" will become stabilised on the actual high level, many river basins in hilly regions of Southwest Germany will have a dramatically increased flood risk." Instationarity does not concern all Germany, but it is a serious regional problem for many river basins of Southwest Germany

REGIONAL ESTIMATION OF HIGH INTENSITY SHORT DURATION RAINFALL EVENTS

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The procedure for regional estimation of excess probability has been applied to high intensity short duration rainfall events in order to evaluate the flood hazard in Ligurian catchments. TCEV - Two Components Extreme Value - probability distribution has shown excellent descriptive and predictive capabilities, as compared with usual EV probability distributions. The determination of scale parameter has been performed by linking ground observed historical data with remote sensing observation of the typical extreme storm structure over the region. The observed variability of the scale parameter across the region suggests that the maximum annual short duration rainfall depth process has its central measure controlled by a simple physics. Convective processes over Liguria region are mainly driven by orographic uplift: the relative angle between the southern slope of the Ligurian Apennines and the direction of largest S-N fetch seems to control the intensity of deep convection. Experimental evidence is presented

The influence of the local catastrophical phenomena in the atmosphere.

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It is well-know that the concentration of the harmful substances in the atmosphere sharply changes during catastrophical phenomena which results in the further alteration of the regional and then global climate. Due to such phenomena as shower- type precipitations, intence rains heavy showing, the atmosphere clears from the harmful substances but at the same time there is a peculiar pollution of the soil, rivers, lakes and then seas and the oceans in the given region. Strong winds which disperse harmful substancesfrom the given region ovev the large territories are also of great importance. In order to study the given problem statistical data of the meteorological valuea for the last 15 years on the territory of Georgia will be analysed using 30 meteorological station.

COMPARISON OF FLOOD FREQUENCY MODELS BASED ON EXTREME RAINFALL ANALYSIS

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Flood frequency analysis often copes with scarcity of hydrometrical data. The use of the whole available hydrological information, both floods and rainfalls recorded in a large homogeneous area around the examined basin, improves design flood estimation. Parametrical methods of identifying these areas have some attraction but could give bad results. Moving from the index flood method, a hierarchical regional approach, employed in the Italian VAPI flood evaluation project, gathers all the extreme hydrological series belonging to an homogeneous area, whose extension depends on the order of an appropriate statistics. Particularly TCEV distribution, employed in this procedure, performs daily rainfall analysis for the identification of homogeneous hydrometric regions and subregions. Moreover hourly rainfall analysis is performed for index flood relationships. The growth curves so obtained are robust enough but attention must pe paid essentially to the regional estimation of index flood. Another interesting approach exploits pluviometric information for flood distribution by assuming rainfall excess fully transformed in runoff volume. This procedure, performed by the French AGREGEE model, fits directly local flood data in lower return period domain. For higher return periods it derives the slope (gradex) of flood distribution from the distribution slope of extreme daily rainfall recorded in a representative site of the basin. The choose of this pluviometric site and the threshold of rainfall data computed for flood gradex estimation are some of the peculiar steps of the procedure. Both AGREGEE and TCEV models assume different behaviour of the flood's CDF for low and high return periods. A more detailed comparison arise from the application of the models on various European hydrological data base.

SCALING OF REGIONAL FLOODS - AN L-MOMENTS APPROACH

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An approach to analyse scaling properties of floods from expected order statistics and L-moments is here developed further with respect to the procedures for determining scale coefficients. A scaling relation has been introduced for the expected order statistics, which allows the derivation of a scale dependence of L-moments, L-moments ratios and of parameters of theoretical distribution functions. The method used to estimate the scale coefficients has a significant influence on the behaviour of the tails of the scaling relation. The effect of this is illustrated on scale dependencies for the GEV distribution, with the EV1 as a special case, applied to a Swiss data set consisting of 182 observation series with at least 20 years of instantaneous floods.

REGIONAL GEOSTATISTICAL ANALYSIS OF VERY EXTREME RAINFALL AND FLOODS

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Natural hydrometeorological disasters in the Mediterranean region are generated in the past essentially by outlying events characterized by extremely large rainfall intensity and rare occurrence. Because of their rare occurrence, these extreme events can be treated only on regional frequency bases, to reduce parameter uncertainties estimation in gauged sites, and for risk evaluation in ungauged sites. A statistical regional model includes (i) a probabilistic model, which can explain the extraordinarily high rainfall and floods observed in the past; (ii) a regionalization model, which can take into account the observed spatial variability of the statistical parameter of the probabilistic model. Here, a regionalization model is shown, based on TCEV distribution probabilisti model, with a geostatistical analysis of its parameters. The regional model considers that the observed variance comes from two sources: sampling variability, due to uncertainties into point estimates, and spatial variability, due to effective difference between sites. Usual geostatistical techniques refe to the exactitude property in gauged sites. At-site estimates are affected by sampling uncertainty, that can be predominant for high order parameters. An iterative procedure is implemented, which allows to obtain the spatial structure of the noiseless variate. First results are shown, with reference to a case study for an Italian region. The objective differentiation between areas with different risk is one of the most important finding of the proposed regionalization procedure.

INCREASING FLOODING RISK CONSIDERING SEDIMENTATION IN THE RESERVOIR

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Reservoirs not only trap the incoming sediment load but also reservoir sedimentation increases the flooding risks because of aggravation upstream of the reservoir. Reservoir sedimentation results in loss of storage capacity for flood control and/or water supply. Sedimentation in reservoirs is a random variable and the value of sediment coming to the reservoir and/or passing the outlet, should be considered as a random variable. In the study a probability distribution function was found for the accumulated sediment in the a reservoir. Therefore the value of accumulated sediment for any year during the life time of reservoir was estimated. Accordingly with considering the initial reservoir capacity, the capacity of the reservoir was estimated for any year after the construction of the reservoir. Obviously the reservoir capacity is decreasing. Applying the Moran's Model for reservoir sizing considering the dependence of reservoir capacity with time, the probability of overflow for every year after construction of the reservoir was obtained. The results of the study shows how the risk of flooding in downstream of the reservoir is increases during the life time of a reservoir.

ANALYSIS OF THE METEOROLOGICAL PATTERNS PRODUCING FLASH FLOOD IN THE IBERIAN PENINSULA

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During October and November 1997, more than twenty people died in the Iberian Peninsula as a result of flash flood. This situation repeats every year. The meteorological patterns that produced the intense rain that resulted in flash flood differ widely. Very intense synoptic patterns like front or cutt-off-lows, mesoescale convective systems or even intense storms can produce flash flood. In this study we analyze the meteorological patterns producing flash flood in the Iberian Peninsula in the last ten years.

REGIONALIZATION OF THE EXTREME ANNUAL RAINFALL USING THE TWO-COMPONENT EXTREME VALUE MODEL : DISCUSSION AND APPLICATION

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This paper presents the regionalization method of maximum rainfall based on the cumulative distribution function (CDF) of the Two-Component Extreme Value (TCEV), developed by Rossi et al (1984) and its application on the daily maximum annual rainfall samples over the region of Minas Gerais (Brazil). This statistical model is based on the product of two exponentials, both representing a Poisson process: the first corresponding to the most frequently maximum rainfall generated and the other corresponding to the outliers . Theoretical aspects of the model are briefly presented and discussed. The regionalisation technique is divided in two parts.The first regionalisation level consists in defining the homogeneous regions.. Working with dimensionless values, the data of the homogeneous regions are pooled together to give a single series of station-year. The second regionalisation level consists in defining sub-regions where the third paremeters of the cumulative distribution function TCEV are constant. The procedure used is a first step to define hydrological homogeneous regions related to the flood frequency studies.

Convener: Brauers, T.
Co-Convener: Schrems, O.

THE ALBATROSS FIELD CAMPAIGN: SETUP AND METEOROLOGICAL CONDITIONS

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From October 5 to November 10, 1996, the field campaign ALBATROSS (Air chemistry and lidar studies of tropospheric and stratospheric species on the atlantic ocean) aboard the research vessel POLARSTERN was carried out in order to examine the atmospheric chemistry processes in the remote marine atmosphere. A comprehensive set of trace gas concentrations and meteorological parameters were measured simultaneously during the cruise which extended from Bremerhaven (53°N) around Iceland (68°N) and finally to Punta Quilla, Argentina (55°S). We will describe the general features of the campaign, sumarize the measurements, the techniques and setup of the instruments on board the ship. The meteorological data, along with in-situ trace gas measurements, such as NOx and ozone, will be used to characterize the nature of the air masses encountered and to provide a classification of the different episodes of the campaign.

SPATIO-TEMPORAL VARIABILITY OF IONIC COMPOSITION OF AEROSOLS, DMSO AND AITKEN NUCLEI DURING THE ALBATROSS CAMPAIGN

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In order to investigate the oxidation reaction of DMS in the marine atmosphere, during the Albatross campaign in the Atlantic ocean, samples were collected for determination of its oxidation products. In this article we will examine the distribution of particulate phase oxidation products: nss-SO4, methanesulfonic acid (MSA) and DMSO collected by using 6-stage impactor. The use of 6-stage impactors in addition allowed us to determine the distribution of the above mentioned species. Very low nss-SO4 concentrations were observed (mean value of submicronic: 5nmol/m3) which indicates that during the biggest part of the experiment we received the influence of pure oceanic air masses.One exception was around the 20th October when the boat was sailing near to Africa. MSA concentrations followed remarkely well the atmospheric DMS concentrations. The variations of DMSO as well those of smaller organic acids, like oxalate and pyrouvate are also presented and their variation are discussed.

MEASUREMENT OF THE HO_X ($OH+HO_2$) PRODUCTION RATE IN THE BOUNDARY LAYER OF THE ATLANTIC OCEAN

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The photochemical production of OH and HO_2 radicals strongly influences the oxidizing capacity of the troposphere. During the ALBATROSS field campaign in Oct./Nov. 1996 on board the german research vessel POLARSTERN we measured the photolysis frequencies of $O_3 \rightarrow O(^1D)+O_2$, $HCHO \rightarrow H+CHO$, and $H_2O_2 \rightarrow 2OH$ using filter radiometers and a calibrated spectroradiometer measuring UV actinic fluxes. In combination with simultaneously measured concentrations of ozone, water vapor, formaldehyde, and hydrogen peroxide in the marine boundary layer we calculate the relative contributions to the HO_x production rate from the different photolytical radical sources. We analyze these quantities with respect to their meridional distribution and for their individual contributions to the budget of HO_x depending on the trace gas concentrations (i.e. ozone and NO_x).

COMPARISON OF HCHO AND SO_2 MEASUREMENTS IN THE BOUNDARY LAYER OF THE ATLANTIC OCEAN

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During the ALBATROSS field campaign aboard the german research vessel POLARSTERN tropospheric SO_2 and HCHO concentrations in the marine boundary layer of the Atlantic Ocean were measured by several experiments. Measurements of the long-path laser absorption experiment DOAS yielded concentrations for both species with typical detection limits of 240 pptv for SO_2 and 770 pptv for HCHO and a time resolution of 5 minutes. During the campaign, SO_2 mixing ratios were also measured using SO_2 filter sampling with a detection limit of 3.6 pptv SO_2 at average time intervalls of 55 minutes. HCHO mixing ratios were determined in 20 minute averages by another experiment using a Hantzsch method instrument with a detection limit of 80 pptv HCHO. Taking into account the different time resolutions, detection limits and methods of the experiments, a careful statistical analysis is conducted to derive a comparable set of data. The consistency of measurements is verified to prepare a closer examination of SO_2 and HCHO mixing ratios in the context of marine tropospheric chemistry.

PEROXY RADICAL MEASUREMENTS IN THE MARINE BOUNDARY LAYER

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The peroxy radicals (RO_2 i.e. HO_2, CH_3O_2, CH_3COO_2 etc.) play an important role in the chemistry of the marine boundary layer. During the day, they lead to a chain reaction which either produces or destroys ozone (O_3) depending on the amount of NO_x molecules present. Peroxy radicals produce via their self reaction peroxides (H_2O_2, CH_3O_2H, etc.), which are important oxidising agents in clouds and raindrops. During the ALBATROSS-campaign (Polarstern cruise XIV/1, Bremerhaven - Punta Quilla) peroxy radicals were measured, with a chemical amplifier designed at the University of Bremen, from 05.10.96 to 10.11.96. The chemical amplifier measures the sum of all oxy- and peroxy-radicals. The main objective was to determine the behaviour of RO_2 in unpolluted (NO_x < 17 pptv) northern- and southern-hemispheric (50°N - 30°S), marine air. A second objective was the validation of the results from the Polarstern cruise ANT X (1991). Diurnal variations with maximum radical mixing ratios of 18 pptv were measured. The resultant production of H_2O_2 from the peroxy radicals has been modelled and compared to measurements taken during the research cruise.

BROAD SCALE VARIABILITY OF DMS IN THE ATLANTIC. ASSESSMENT OF SOME CONTROLLING FACTORS

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To better understand the meridional variability of the DMS sea surface concentration and its controlling factors, DMS was measured concomitantly with particulate and dissolved forms of dimethylsulfoniopropionate (pDMSP and dDMSP), phytoplanktonic pigments and cell numbers, during the ALBATROSS-MARATHON campaign across the Atlantic (from 65°N to 45°S). The spatial resolution along 30°W was about 150 km. The DMSPd/DMSPp and DMS/DMSPp ratios decreased poleward as the SST and contrary to marine productivity, excluding in this latter case most of the tropical waters (20°N-10°S). In the mesotrophic waters north of 45°N and south of 35°S (ChLa > 0.1 µg/l), pDMSP and Chla were highly correlated as the pDMSP size fractions <10 µm and >10 µm with the pigments 19'HF and peridinin of prymnesiophytes and dinoflagellates respectively. In the 45°N-35°S zone, the pDMSP/CHLa ratio was highly variable and culminated in the oligotrophic waters. These results highlight the strong similarities between the meridional distributions of pDMSP and of phytoplanctonic carbon.

FIRST ATLANTIC MERIDIONAL TRANSECT OF SEA SURFACE DMS CONCENTRATION ALONG 30°W WITH 15 KM OF SPATIAL RESOLUTION

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During the ALBATROSS-MARATHON campaign across the Atlantic aboard Polarstern in Oct./Nov. 1996, 920 measurements of DMS were carried out at sea surface between 65°N and 45°S along 30°W, with a spatial resolution of about 15 km. This has helped the understanding of the role of mesoscale hydrographic structures (fronts, eddies and currents) in the surface budget of oceanic DMS. The spatial distribution of DMS in the subtropical and intertropical Atlantic was strongly influenced by the presence of fronts which showed DMS levels at least twice and up to 20-fold higher than in the non frontal areas. In the subtropical areas during spring and autumn, fronts contributed to the reduction of the poleward negative gradient of DMS concentration. In the intertropical zone they markedly enhanced the high DMS background typical of the area. The ALBATROSS-MARATHON high resolution oceanic DMS dataset has been used to estimate the DMS emissions to the atmosphere and to investigate the fate of DMS in the remote marine troposphere (J. Sciare et al., this session).

COMPARISON OF LONG–PATH LASER ABSORPTION AND LASER INDUCED FLUORESCENCE MEASUREMENTS OF OH RADICALS IN THE MARINE ATLANTIC BOUNDARY LAYER

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The concentration of free hydroxyl radicals in the marine boundary layer of the Atlantic Ocean was simultaneously measured by *long–path laser absorption spectroscopy* and *laser induced fluorescence spectroscopy* during the ALBATROSS campaign aboard the German research vessel POLARSTERN. The long–path instrument provides an absolute and calibration free measurement of OH, whereas the LIF instrument needs calibration in the field.
Both instruments were placed 18m apart on the compass deck and probed the air at a height of 29 m above the sea. The absorption instrument used a light path of 2240 m folded into a multiple reflection cell with a mirror separation of 20 m. Temporally overlapping OH data of both instruments are available for 7 days in a latitudinal range between 5 °N and 30 °S. We compare all diurnal profiles of OH measured concurrently with both instruments. The correlation of the OH data sets allows a careful check of the calibration procedure applied for the LIF instrument. The data comparison will be discussed in terms of calibration uncertainties and possible interferences by ship exhaust.

Levels and patterns of semivolatile organohalogenated compounds in marine air of the Atlantic Ocean

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Chlorinated hydrocarbons have been produced since the early thirties for different purposes. Through the application they were brought into the environment, intentional or unintentional. Usually the atmosphere is considered to be the major pathway for this environmental chemicals to previously uncontaminated areas. They are distributed between atmosphere, hydrosphere, sediments and biosphere on a finally global level, governed by their physico-chemical properties. The complex process of distribution and accumulation may be superimposed by abiotic and biotic transformations. The following compounds were quantified in air samples of the tropospheric boundary layer of the Atlantic Ocean: polychlorinated biphenyls (PCB), hexachlorocyclohexane-isomers (HCH), chlorobenzenes (PCBz, HCB), members and metabolites of the DDT-group, and of the cyclodien-insecticides. The samples were taken during a north-south cruise of the german research vessel "Polarstern" in autumn 1996. If long distance inputs from continental sources can be excluded, the patterns of the investigated chemicals in the marine clean-air reflect the air/sea water equilibrium. The knowledge of this partition coefficient is very valuable for the prediction of a global behaviour. The mentioned environmental chemicals are present in marine air in concentrations down to a few picograms per m^3 air. The necessary enrichment for their determination was achieved by adsorptive high volume air sampling on graphit covered silica gel. Sample preparation was done by solvent desorption, preseparation by liquid adsorption chromatography on silica gel and by high resolution capillary gas chromatography with electron capture detection (HRGC/ECD).

ALKYL NITRATES AND MULTIFUNCTIONAL ALKYL NITRATES IN REMOTE ATLANTIC AIR

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Alkyl nitrates are complex mixtures of homologues and isomers and are part of the large NO_y pool of important atmospheric trace compounds. The source of alkyl nitrates in the troposphere is the conversion of hydrocarbons in the reaction chain with $OH/H_2O//O_2//NO$. This reaction scheme may repeat itself leading to keto alkyl nitrates or to alkyl dinitrates. Alkenes lead via the reaction with OH or NO_3 preferably to multifunctional organonitrates like the hydroxy alkyl nitrates or the alkyl dinitrates. The atmospheric lifetimes are in the range of some weeks and allow therefore a long range transport to the unpolluted marine troposphere.
Alkyl nitrates with chain lengths up to eight carbons, alkyl dinitrates, and alkyl hydroxynitrates with chain lengths up to six carbons have been detected in the remote troposphere of the Atlantic Ocean along 30°W of longitude on the german RV Polarstern (Cruise ANT XIV/1), by adsorption on Tenax TA. The analysis was performed after thermal desorption on a polar stationary phase (DB 1701) by HRGC with electron capture detection. C_3-C_5 alkyl nitrates show low concentrations in clean marine troposphere of 3 pptv and higher concentrations reveal the influence of the continental air (e.g. 8.4 pptv in the west wind belt, influenced by the south american continent) as the source of the alkyl nitrates after long range transport.

THE LATITUDINAL DISTRIBUTION OF HYDROCARBONS AND HALOCARBONS DURING THE ALBATROSS-CAMPAIGN

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During the cruise of the German research vessel 'Polarstern' (ANT XIV/1, October/November 1996) the latitudinal distributions of CO, light nonmethane hydrocarbons (NMHC) and halogenated C_1 - C_2 hydrocarbons were measured in the boundary layer over the Atlantic. The measurements covered a latitude range between 65°N and 45°S. Carbon monoxide was measured in-situ, while NMHC were measured from one hundred whole air samples collected in stainless steel canisters. Highest mixing ratios for most of the determined compounds were observed in the Northern Hemisphere in the latitude range from 45°N to 65°N. On average, ethane, propane and acetylene mixing ratios were about 1000 ppt, 300 ppt and 150 ppt, respectively. Trajectory analyses indicated that the air masses originated from the North American continent. Between 40°N and 30°N a minimum in the mixing ratios of these compounds was observed. During this part of the cruise remote mid-Atlantic air masses were sampled. For light hydrocarbons and halocarbons, except methylchloride, a pronounced gradient was found in the latitude range from 30°N to the intertropical convergence zone (ITCZ). In the Southern Hemisphere the mixing ratios of CO and NMHC were almost constant at extremely low levels.

ORGANIC COMPOSITION OF MARINE AEROSOLS OVER THE ATLANTIC OCEAN: STUDY OF THEIR ORIGIN AND OCCURRENCE DURING THE ALBATROSS CAMPAIGN.

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Atmospheric organic constituents in the marine remote atmosphere has been compiled in order to reconcile their sources, transport processes and fates after long-range transport. Airborne particulate samples were collected by high-volume filtration on October 1996, during the Albatross cruise across the Atlantic ocean. In this study the hydrocarbon series, namely the aliphatic hydrocarbons, included n-alkanes and an unresolved complex mixture of hydrocarbons (UCM), and the polyaromatic hydrocarbons (PAHs) will be presented. n-Alkanes were found in low concentrations, and they ranged from C_{17} to C_{33} with an odd-to-even carbon number predominance, indicating an origin from terrestrial plant waxes. PAHs, mainly of anthropogenic origin were minor constituents during the whole experiment. Moreover, the use of 6-stage imactor allowed the observation of an episode of transport from the African coast and the correlation of biogenic and antropogenic organic matter with different-sized particles.

UV-B RADIATION MEASUREMENTS OVER NORTHERN AND SOUTHERN ATLANTIC

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During the ALBATROS campaign continuous atmospheric UV-B measurements were made aboard the research vessel Polarstern. Data were collected from October 10 to November 11, 1996 during an Atlantic transect from 65o N to 50o S followed by a second cruise from November 14 to December 30, 1996 from 54o S to 62o S. The UV-B instrument was a non-scanning array spectroradiometer operating with 32 independent photon-counting channels (microchannel plate detector). Due to the high stability calibrations were necessary only before and after the cruise.

The UV-B radiation measurements have been correlated with stratospheric ozone and other trace gases measured simultaneously during the campaigns. The results show short term ozone variations depending on the geographic latitude. In 1997 the data were supplemented from October 15 to November 7 with additional measurements during a further cruise from 50o N to 35o S. The data have been campared with the results of the ALBATROS campaign.

FACTORS CONTROLLING THE OBSERVED SEASONAL VARIATION OF SURFACE OZONE AT AMSTERDAM ISLAND.

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Since January 1994, continuous surface ozone measurements are carried out at Amsterdam island (37°S, 77°E) in the Southern Indian ocean using a Thermo-Electron Model 49 UV analyser. Mean ozone concentrations and standard deviations are recorded every five minutes. The ozone time series for the four years period (1994-1997) will be shown and discussed. During this period, ozone shows a seasonal variation with maxima around 30 ppbv during winter (July to September) and minima around 13 ppbv during summer (December to February). Ozone levels at Amsterdam island are close to those observed at Cape Grim (Tasmania, 41°S, 145°E) for the period of 1991 to 1995. Our observations have been analysed by using a global 3D climatological model MOGUNTIA. The model is reproducing well the observed O_3 mixing ratios and their seasonal cycle. MOGUNTIA will be used to identify and quantify the contribution of different factors on the O_3 seasonality : stratospheric influx of O_3, NMHC chemistry and biomass burning emissions of O_3 precursors (long range transport).

MEASUREMENTS OF THE OH AND HO_2 CONCENTRATIONS IN THE MARINE BOUNDARY LAYER DURING ALBATROSS USING LASER-INDUCED FLUORESCENCE SPECTROSCOPY

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Atmospheric hydroxyl (OH) and hydroperoxyl (HO_2) radical concentrations were measured during the ALBATROSS field campaign aboard the german research vessel POLARSTERN in October 1996 in the marine boundary layer of the Atlantic Ocean. Measurements extended from 30° N to 30° S mainly along the meridian 30° W and covered a time period of 14 days. The highly sensitive technique of laser-induced resonance fluorescence spectroscopy (LIF) in an expanding gas beam of ambient air at low pressure was used to detect OH radicals in ambient air. In a second fluorescence cell NO was added to convert about 70 % of the HO_2 radicals into OH. The fluorescence signal detected in this channel therefore was a measure for both, OH as well as HO_2 (= HO_x) radicals. Diurnal cycles of both radicals were measured in parallel with a typical time resolution of about 2 min. Usually the ambient air measurements started before sunrise and ended after sunset. During the night time hours the instrument was calibrated. However, on single occasions the ambient air measurements were carried on into the night yielding a HO_x signal well above the detection limit of our instrument. The diurnal cycles of OH and HO_2 and the night time measurements will be presented. Correlations of the radical concentrations with different photolytic production pathways will be discussed.

MEASUREMENTS OF THE OH CONCENTRATION IN THE BOUNDARY LAYER OF THE ATLANTIC OCEAN BY DIFFERENTIAL OPTICAL ABSORPTION SPECTROSCOPY

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Simultaneous measurements of the concentration of OH radicals, SO_2 and HCHO in the marine boundary layer were performed during the ALBATROSS field campaign aboard the German research vessel POLARSTERN. Laser long-path absorption along a 112-times folded light path of 2.24 km total length, set up about 30 m above the sea surface, was applied. This paper presents results of the OH measurements. In total 600 OH data points were recorded along the 30th meridian between 5° N and 35° S. Maximum OH concentrations were found at local noon varying between 6.5×10^6 cm^{-3} and 9.5×10^6 cm^{-3}. The measurement limit was about 1.0×10^6 cm^{-3}. The time series of the OH concentration is presented and a first analysis is discussed.

CHEMICAL PROCESSES AND INTERACTION WITH TRANSPORT IN THE MARINE TROPOSPHERE. AN OVERVIEW.

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The oxidant chemistry of the marine troposphere has a major impact on the cycles of sulfur, nitrogen, and carbon species. Main features of the atmospheric chemistry of hydroxyl and halogen radicals are described.
Experimental indications for interaction of chlorine atoms with ozone and dimethylsulfide (DMS) chemistry will be reviewed. The implications of these processes for the trace gas budgets in the marine troposphere are speculated on the basis of model results.
Data on the oxidation of hydrocarbons and DMS in the clean atmosphere are examined with respect to observations of relevant trace compounds. Perturbations of the marine atmosphere by anthropogenic and more generally continental emissions of trace gases and particles are demonstrated based on observations and on the results of chemistry/transport models.

How well can we simulate the atmospheric chemistry of the marine boundary layer of the Atlantic ocean?

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The Albatross/MARATHON experiment performed in the Atlantic ocean in Oct-Nov 1997 consists a unique opportunity to evaluate 1) the current understanding of the key chemical processes occurring in the marine boundary layer (MBL) and 2) the ability of chemical transport models to simulate atmospheric chemistry in the MBL. Indeed, an important set of chemically reactive trace compounds including the OH and HO2 key radicals for tropospheric chemistry has been measured mainly in pure oceanic air masses.Zero-dimensional and three-dimensional modelling approaches have been used to address crucial questions for the MBL chemistry concerning 1) the correctness of the simulations of the levels and the diurnal variation of HO2 and OH radicals, 2) the N-S distribution of O3 and CO, 3) the reconciliation of the observed atmospheric concentrations of DMS with the measured DMS fluxes from the ocean and the observed OH radical levels and 4) the coherence between the distribution of DMS oxidation products SO2, MSA, DMSO and the known routes of DMS oxidation. The comparisons between model results and observations are presented and thoroughly discussed.

ALKYL NITRATES - TRACE CONSTITUENTS OF THE MARINE TROPOSPHERE

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Organic esters of nitric acid, known as alkyl nitrates or organo nitrates, which are considered to be components of the so called photochemical smog, are built by the atmospherical degradation of hydrocrbons in the atmosphere [1]. In the last years, efforts were made to detect these substances in polluted and pristine air as well, focussing on short chain alkyl mononitrates of continental air masses. Only a few reports of measurements of alkyl nitrates in the marine troposphere were published up to now [2-4]. These first investigations make it likely that there exist distinct differences in the alkyl nitrate patterns of marine air masses compared to continental ones. The concentrations of primary alkyl nitrates relatively to secondary ones seem to be much higher in marine air compared to continental air [6]. In this paper we present results obtained from analysis of marine air of the Atlantic Ocean collected during cruise ANT XIV/1 of the German *RV Polarstern* from Bremerhaven (Germany) to Punta Quilla (Argentina) in october/november 1996. A high volume technique was applied to collect mono- and multifunctional alkyl nitrates, respectively, using silicagel and graphitized silicagel as adsorbent materials. The clean-up step was performed by HPLC with an organo nitrate stationary phase synthesized in our own laboratory [6]. Separation and identification of single substances was done by HRGC-ECD and HRGC-MSD on polar and non-polar sationary phases. Disturbing peaks could be eliminated to a high degree by running the mass spetrometer in the single-ion-monitoring mode using the m/z-ratio 46 amu which indicates the existence of the NO_2^+-ion which is characteristic for alkyl nitrates.

MEASUREMENTS OF SO_2 AND NSS-SO_4^{2-} OVER THE ATLANTIC OCEAN DURING ALBATROSS: A CASE STUDY ON THE KINETICS OF THE SO_2 OXIDATION IN THE MARINE BOUNDARY LAYER.

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Measurements of sulfur dioxide (SO_2) and non-sea-salt sulfate (NSS-SO_4^{2-}) were performed on board of the RV "POLARSTERN" in 10/11 1996 as part of the ALBATROSS measuring campaign. The measurements cover a latitudinal range from 66.7°N to 37.8°S. Compared to publications of other authors distinctively lower background concentrations of SO_2 have been observed in the marine boundary layer (MBL) over the Atlantic ocean. Background values were found to be 0.85 nmol m^{-3} (19 pptv) for SO_2 and 7.42 nmol m^{-3} for total NSS-SO_4^{2-}. The size fractionated aerosol samples (d > 1 μm and d < 1 μm) of NSS-SO_4^{2-} show that an average of 33% of the total NSS-SO_4^{2-} exists in the particles with d > 1 μm. According to the studies of *Sievering et al.* (1991), the main fraction of this NSS-SO_4^{2-} is produced by heterogeneous oxidation of dissolved SO_2 via O_3 in the sea-salt aerosol-water of coarse mode particles.
Trajectory analysis as well as measurements of specific tracers indicate that on 10/12/96 the ship was in the plume of a volcano which erupted on Iceland during the cruise. This provided the unique opportunity to study the kinetics of the heterogeneous oxidation of SO_2 by O_3 in the MBL with an empiric physico-chemical approach by considering the atmosphere as a natural flow reactor. The results of this kinetic study will be presented.

TOTAL COLUMN DENSITY MEASUREMENTS OF ATMOSPHERIC TRACE GASES BY SOLAR ABSORPTION SPECTROSCOPY

J. Notholt (1) and O. Schrems (2)
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During the ALBATROSS campaign in 1996 total column density measurements of atmospheric trace gases have been performed by solar infrared absorption spectroscopy for the first time aboard a ship by means of a high-resolution FTIR spectrometer. The spectra have been recorded with the commercial Bruker 120M FTIR spectrometer up to a resolution of 0.0038 cm^{-1}. The meteorological conditions during the ship cruise permitted to record spectra from 50°N to 40°S.

The analysis of the spectra allowed to quantify the total columns of several tropospheric (e.g. CO, CH_4, C_2H_6, CH_2O, CFC-12, CFC22) and stratospheric trace gases (e.g. HCl, NO_2, HNO_3, O_3, NO_2). For some trace gases a profile retrieval could be performed by dividing the atmosphere into several layers. The total columns of the long-lived tropospheric trace gases (N_2O, CH_4, CFCs) are mainly influenced by variations of the tropopause altitude. The results for the reactive tropospheric trace gases show strong variabilities, which are assigned to biomass burning (e.g. CO) or to pollution of anthropogenic origin in the northern hemsiphere (C_2H_6).

LIDAR OBSERVATION OF AEROSOL IN THE TROPOSPHERE BETWEEN 20°N TO 30°S ABOVE THE ATLANTIC OCEAN

P. Rairoux (1), R. Neuber (1), O. Schrems (2), S. Frey (3), L. Wöste (3)
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Lidar observations of tropospheric aerosols were performed during the ALBATROSS 1996 campaign aboard the research vessel "POLARSTERN" on the Atlantic ocean in October-November 1996. The Lidar (Light detection and ranging) is a suitable technique for the aerosol vertical sounding from 400 m above sea level up to the tropopause. During this campaign, measurements were recorded between 20°N to 30°S along the 30°W longitude. The following observations were retrieved from these measurements: -The longitudinal distribution of the maritime atmospheric boundary layer height and the thickness of the entrainment zone above this layer. -The vertical distributions of the aerosol mass mixing ratio along the 30°W longitude that show long range aerosol rich air masses transport from the African and American continents. -The frequent formation in the tropical region of high altitude cirrus clouds located close to the tropopause.

SPATIO-TEMPORAL VARIABILITY OF ATMOSPHERIC DMS, SULFUR DIOXIDE, NITRIC ACID, AMMONIA AND ORGANIC ACIDS DURING THE ALBATROSS CAMPAIGN

J. Sciare (1), E. Baboukas(2), G. Kouvarakis (2), S. Belviso (1) and N. Mihalopoulos (2).
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During the Albatross campaign one hundred and thirty (130) atmospheric samples have been collected between 58iN-38iS and immediately processed to measure DMS concentrations. Atmospheric DMS concentrations were ranged from 20-260 pptv. The lowest atmospheric DMS concentrations were observed around 55iN and 38iS and are in line with the low DMS values measured in seawater in the above areas. Wind speed seems to be an important factor controlling the atmospheric DMS concentrations. Clear diurnal variations have been observed (mainly under clear sky conditions) for atmospheric DMS with the lowest concentrations between 12-18h. In order to investigate the oxidation reaction of DMS in the marine atmosphere, samples were collected for determination of its oxidation products. In this article we will examine the distribution of gas phase oxidation products: SO2 collected by using the denuder technique and DMSO by using the mist chamber technique. The extract of the denuders has been also used for simultaneous determinations of gas phase concentrations of HNO3, NH3 and organic acids. The results of the thirty one (31) denuders collected during the whole trip are presented and their variation is discussed.

LIDAR MEASUREMENTS OF TROPOSPHERIC WATER VAPOUR OVER THE ATLANTIC DURING THE ALBATROSS CAMPAIGN

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(2) Forschungszentrum Jülich, FRG
(3) Jet Propulsion Laboratory, California Institute of Technology, USA

In this contribution we will report results of water vapour measurements over the Atlantic Ocean with a new mobile Raleigh Raman lidar instrument (MARL). The data were obtained during the ALBATROSS campaign aboard the German reseach vessel Polarstern in October and November 1996.

The water vapour measurements were performed by comparing the 408 nm H_2O water vapour Raman channel and the 387 nm N_2 Raman channel from the transmitted wavelength of 355 nm. Both signals are proportional to the density of H_2O and N_2, respectively, and thus the water vapour volume mixing ratio can easily be calculated. However, a calibration with radiosonde or other data is necessary to get absolute values. Good agreement has been obtained by comparing our lidar data with data obtained from radiosondes.

The MARL lidar is capable of measuring the variability of the water vapour content throughout the troposphere up to 10 km altitude with a time resolution of about 15 minutes and a height resolution of 120 meter.

THE ALBATROSS CAMPAIGN 1996: AN ATMOSPHERIC CHEMISTRY STUDY OVER THE NORTHERN AND SOUTHERN ATLANTIC (OVERVIEW)

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A summary will be given over the research activities of the ALBATROSS campaign which took place from October 5 to November 10, 1996. ALBATROSS has been an atmospheric chemistry campaign with the German research vessel Polarstern which startet in Bremerhaven (Germany), surrounded Iceland, sailed towards south and finally arrived in Punta Quilla (Argentina).

The main objective of the ALBATROSS campaign was to obtain information for a better understanding of the transport, transformation and deposition of continental emissions, especially hydrocarbons, CO, NOx, SO_2, etc. and resulting reaction products such as O_3, OH, H_2O_2, $RONO_2$, HNO_3, sulfate aerosol, etc..

The investigations of the research groups who participated in the ALBATROSS campaign provided highly valuable contributions to the the international activities such as NARE (North Atlantic Regional Experiment), GLOCHEM (Global Atmospheric Chemistry Survey) and MARATHON (Marine Atmosphere Oxidation Capacity Experiment).

OZONE HEIGHT-PROFILE MEASUREMENTS OVER THE ATLANTIC OCEAN ALONG THE 30° W MERIDIAN WITHIN THE ALBATROSS PROJECT

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During the XIVth journey of the *RV Polarstern* from Bremerhaven to Antarctica ozone vertical profiles were measured over the Atlantic Ocean along a transect between 65° N and 45° S following the 30° W meridian. The measurements which were part of the project ALBATROSS and thus of the North Atlantic Regional Experiment (NARE) were carried out with the differential-absorption lidar ARGOS. Each day between 10 October and 5 November 1996 several profiles of usually 1 h duration were taken; the height region that was sampled was between 50 and 2 500 m above sea level. Because of the highly inhomogeneous distribution of the atmospheric backscatter coefficient, typical uncertainty values were occasionally as high as 10-30 $\mu g/m^3$. Additional information on the aerosol distribution in the marine troposphere was derived from the lidar backscatter signals. In spite of frequent clouds ozone profiles could be obtained up to a height of 2 000 m. High concentrations, well above 60 $\mu g/m^3$, were measured between 50 and 45 and between 30 and 25° N, with a total-mission average around 40 $\mu g/m^3$. Except for a decrease close to the sea surface, the ozone concentration varied remarkably little with height. Back trajectories showed that periods of high ozone correlated with short travel times of the air masses from a continent to the place of the measurement. Another, weaker correlation was found with wind speed: positive for continental, negative for marine air masses. No systematic diurnal variations could be noticed that were not masked by the two effects mentioned previously. The height-averaged lidar data generally agree well with the results of in-situ ozone measurements.

HYDROPEROXIDES AND FORMALDEHYDE IN THE MARINE BOUNDARY LAYER OF THE ATLANTIC (48°N-35°S) MEASURED DURING THE ALBATROSS CAMPAIGN

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Hydroperoxides and formaldehyde (HCHO) have been measured in situ during October/November 1996 on board RV *Polarstern* in surface air over the Atlantic from 48°N-35°S. Organic hydroperoxides except of CH_3OOH (MHP) could not be detected during the campaign. Hydroperoxides and formaldehyde mixing ratio were highest within the tropics with peak values of around 2000 pptv (H_2O_2), 1500 pptv (MHP) and 1000 pptv (HCHO). In case of H_2O_2 and MHP we could observe diurnal variations of the mixing ratios and derived deposition rates of around $(1.8\pm0.6)\times10^{-5}\ s^{-1}$ for H_2O_2 and $(1.2\pm0.4)\times10^{-5}\ s^{-1}$ for MHP. The measured MHP/(H_2O_2+MHP) and MHP/HCHO ratios corresponded to 0.32±0.12 and 0.87±0.4, respectively. HCHO mixing ratios observed during the expedition were significantly higher than predicted by current photochemical theory and pointed at the need of further kinetic and mechanistic studies on the reactions $CH_3OOH+OH$ and $CH_3O_2+HO_2$.

A LATITUDINAL CROSS SECTION OF COS CONCENTRATIONS IN THE MARINE BOUNDARY LAYER AND SURFACE WATERS OF THE ATLANTIC OCEAN IN FALL 1997

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COS mixing ratios in the marine atmosphere and the surface sea waters of the Atlantic Ocean were measured during the cruise ANT XV/1 of the German research vessel Polarstern in October and November, 1997. A Teflon diaphragm pump was used to collect the marine air from the crow's nest (~20m a.s.l.) of the ship in Tedlar bags. A Weiss type equilibrator was used to extract the dissolved COS from sea water collected 5m below the sea level. The marine air and less than 3% of the headspace air in the equilibrator were cryogenically enriched and then analysed for COS using gas chromatography with a flame photometrical detector (GC/FPD). The COS mixing ratio averaged 501±35 pptv in 178 air samples covering a latitudinal range from 50°N to 30°S. The latitudinal distribution of COS in the marine boudary layer was found to be uniform, with no significant interhemispheric gradient. The COS concentration in the sea water ranged from 3.9 to 60.4 $pmol \cdot L^{-1}$ and showed clear diurnal variations, especially on sunny days. In comparison to the overlying air, the sea water was found to be undersaturated with COS between midnight and sunrise and supersaturated during other times of the day, implying that the ocean could act both as a source and a sink for COS. The calculated COS saturation ratio varies from 0.5 to 6.3.

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